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COST OF PRODUCING DRY MILK IN LARGE  
SCALE PLANTS UNDER NEW TECHNOLOGY

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by

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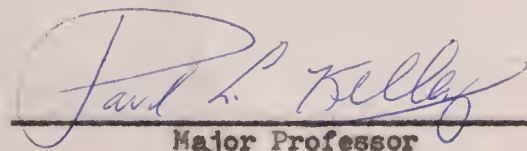
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## I. INTRODUCTION

### Background

Since World War II, the process of drying skim or whole milk has been of major importance to the dairy processing industry. During the wartime period government economic planners sought to encourage delivery of whole milk by farm producers to dairy manufacturing plants. This particular policy was an outgrowth of the government's attempts to achieve greater efficiency in the use of fluid milk as a food product. Commodity prices were set to make operations associated with farm separated cream less profitable than those associated with plant separation. This policy led to a rapid expansion in drying capacity over the entire United States during the World War II period. Plants that formerly processed farm separated cream added fluid receiving facilities and equipment for separating and evaporating in addition to dryers.

Following the wartime period there were further adjustments affecting the interest of the dairy manufacturing industry in milk drying technology. There were steady shifts of population from the eastern to the southwestern portions of the United States with increased grade A requirements to be met for these sections. The large wartime demand for condensed milk slackened and some of the milk supply used for condensed operations was diverted to butter and nonfat dry milk.

Another development added to the already expanded interest in milk drying technology. Cooperatives and producer associations began to assume greater responsibility for the milk procurement function. Many of these organizations began to take title to the fluid milk and to exert control over the supply to dairy manufacturers. This led to a strengthening of the producer's price bargaining position. However, it also resulted in the release of direct responsibility by many processing plants for handling surplus quantities of fluid milk. This in turn led to increased interest by cooperatives and producer's associations in means for handling and processing surplus quantities of fluid milk.

There has been considerable growth in the size of the milk drying processing plants in the southwest in comparison to the size of butter production facilities. Likewise there has been the introduction of a limited number of specialized milk drying plants in the northern dairy states such as Minnesota.

Milk drying capabilities of the industry still seem to be in an expansion stage with present technology more often characterized by undercapacity in many areas rather than overcapacity. It appears that there is a real interest in the opportunities for the use of large scale, efficient drying equipment in the industry because of the trends outlined above.

#### Problem Statement

The dairy industry has been characterized as expanding in terms of individual plant size; the number of plants is decreasing but their individual size is increasing. There is constant expansion of the

procurement function with a consolidation of supplies being acquired by those plants capable of the most efficient handling methods.

The problem facing many plant managers can then be stated as one of shortages in the capacity of the existing drying facilities and steadily expanding operations. Their decision must be made from among the three following alternatives:

1. Merger of present supplies with those of other processing plants having adequate drying capacity,
2. Provision for increased volume by the remodeling of present facilities to provide for a duplication of present low capacity drying technology, and
3. Installation of new plant facilities incorporating new, higher capacity drying technologies.

In order to permit accurate evaluation of these alternatives management must be provided with accurate information pertaining to the newer technologies. In particular, costs of acquisition and the cost curve that can be expected under specified conditions at various levels of production must be detailed.

This presentation of the problem area can be summarized for this study by two major hypotheses:

1. Acquisition costs for the newer, larger capacity facilities are not prohibitive, i.e., they do not constitute an effective barrier to entry into the industry, and
2. The processing cost curves for the new facilities are such that an investment in such new facilities can be amortized in a relatively short period of time given an adequate



milk supply and existing factor and product prices.

### Objectives of the Study

Three objectives were set for this study:

1. To provide a description of the new facilities and technology selected for this study and an estimate of the capital costs for the acquisition of such a plant,
2. To present the processing costs that could be expected for the type of facility selected under specified operating conditions, and
3. To present a comparison of the operating costs of the new facility to those of existing technology.



## II. METHODOLOGY

### Analytical Approach

The type of analytical technique used for this study has been described as an "economic-engineering approach."<sup>1</sup> In general, the framework of definitions used for the selection and evaluation of data was based upon "economic" concepts and definitions. Derivation of all primary data was made from the case study plant whenever the technique for measurement lay within the means of this study. When this was not the case, however, estimates were made from the "engineering" approach.

The engineering method of determining inputs and applying prices to these inputs in order to determine individual input costs has been described in the following manner:

The engineering method is a system of cost determination wherein the physical inputs are derived from: (a) engineering performance data such as the efficiency factors for steam generation and electric power output under various conditions, (b) chemical determinations of the characteristics of physical inputs such as fuels and steam, (c) thermodynamic theorems concerning rates of heat transfer through different mediums, (d) institutional arrangements such as labor organization, (e) judgement of technologists and researchers familiar with the area of study under consideration, and (f) research findings of time and motion studies in dairy plants.

The above sources of information are utilized to construct formulae and criteria for the determination of the quantity of

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<sup>1</sup>B. C. French, L. L. Sammet, and R. G. Bressler, "Economic Efficiency in Plant Operations with Special Reference to the Marketing of California Pears," Hilgardia, XXIV, No. 19 (July, 1956), p. 580.

physical inputs required to produce a given quantity of output. These derived physical inputs are combined in a resource combination which would be feasible in an actual plant.<sup>1</sup>

In those situations in which it was necessary to synthesize data the specifications of equipment manufacturers were used in conjunction with applicable engineering formulae. The resulting blend of empirical and engineering data sources yields a model which lies somewhere between that of the strictly case study approach and that of the strictly synthetic approach. However, since the synthetic data of this study were checked against general operating results whenever possible, it is hoped that the resulting "blend" model will be appreciably more representative of conditions experienced by an operating plant than would be an exclusively synthetic model.

There have been four specific types of engineering studies defined which are useful in obtaining basic cost data in situations in which they are not available from accounting records. These are:

"(1) detailed descriptions of plant operations; (2) time studies; (3) work sampling studies; and (4) analysis of standard work data."<sup>2</sup>

The type of engineering study selected for use in this study in instances where data were not otherwise available was the "detailed descriptions of plant operations" method. At the outset of the study the possibility of using either time studies or work sampling studies was considered. It was decided, however, that the additional expense would not be justified by the potential gains in precision in this instance.

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<sup>1</sup>Lee Kolmer and Henry A. Homme, Spray Drying Costs in Low-volume Milk Plants (Ames: Iowa State College, n.d.), p. 6.

<sup>2</sup>French, Sammet, and Bressler, 581.

The general nature of the case study plant operation lent itself well to analysis without work sampling. The total labor requirement for the milk drying process studied was occupied with various job assignments within the process during the applicable part of the working day. This fact helped to offset the necessary degree of arbitrariness with which some work assignments were made. Since each of the job locations in question were allocated to the same final product, a misallocation of labor between the assignments, due to lack of information, did not affect the net labor requirement or the final average cost figure.

#### Mathematical Model

Two broad cost categories were defined for this study. One set of costs was defined as fixed for an annual time period. The second set of costs was derived from costs incurred during what was termed a "production run" which generally consisted of a one-day operation period.

Annual fixed costs were computed for the model plant in the conventional manner which will be detailed later. To establish the production run costs, plant operations were stratified by major "processing stages" such as evaporating, drying, bagging, storing, truck loading, and railroad car loading. Within each of the major stages specific substrata termed "production run phases" were defined. For example, in the evaporating stage there were included such phases as hookup of equipment, operation of equipment, shutting-down of equipment, etc.



Within each specific phase, all sources of production run costs were defined. For example, sources of costs in the hookup phase of stage I (evaporating) included such items as class A labor, electricity, water and chlorine. These sources of costs were termed "cost elements."

This procedure was followed for all phases within the stages. There were many similar types of basic costs within phases of given stages that could be aggregated to stage totals in order to simplify cost presentation. For example, electricity consumption in the several phases of the evaporating stage could be aggregated to a stage total for electricity. This procedure was followed for the aggregation of all cost elements.

These procedures can be summarized in a mathematical presentation. The mathematical model for this study is based upon economic definitions for total cost (TC) and average total cost (ATC), and an assumption of a linear relationship between total cost and output (Q).

Total cost (TC) for a given quantity (Q) of product is defined to be the sum of total fixed cost (TFC) and total variable cost (TVC):

$$TC = TFC + TVC \quad . \quad (1)$$

Average total cost (ATC) per unit of output is defined to be the quotient of total cost (TC) divided by the units of output (Q):

$$ATC = \frac{TC}{Q} = \frac{TFC + TVC}{Q} = \frac{TFC}{Q} + VC \quad (2)$$

where:

$$\begin{aligned} VC &= \text{a constant per unit of product (Q),} \\ &= \frac{TVC}{Q} \quad . \end{aligned}$$

All costs will be stated on the basis of a unit of powder output for a specified time period. The unit of measurement selected

for powder output is a hundredweight (cwt.), and an annual time period is specified.

In particular, for this analysis, the relationship between total cost and output is assumed to be linear and stated in general notation as follows:

$$W = a + bQ \quad (3)$$

where:

$W$  = dependent variable (total cost),

$a$  =  $Y$  intercept (total fixed cost),

$b$  = slope (variable cost per unit of product), and

$Q$  = independent variable (units of product produced).

This basic relationship will be applied to the two specified time period definitions which mark the major subdivisions in the analysis of this study. The application of the above general linear model to an annual time period will produce the following specific relationship between total annual cost ( $TC_i$ ) for a particular product and its cost components:

$$TC_i = a + b_i X \quad (4)$$

where:

$TC_i$  = total annual cost for the  $i$  <sup>th</sup> product,

$a$  = total annual fixed cost,

$b_i$  = annual variable cost per day for the  $i$  <sup>th</sup> product where output per day is defined as some constant, and

$X$  = number of annual operating days.

This cost relationship is specified for a particular final product, as all the cost relationships will be for this study. Since costs are considered for an annual time period, this is equivalent to



assuming that the plant will be limited to production of but a single product for an annual time period.<sup>1</sup>

The linear model will be applied again in deriving the above "b" term for the daily time period. This will reflect recognition of the fact that costs which can be variable annually by varying the number of operating days (or production runs) may also have a certain degree of fixity during any given operating day. The linear model as applied to an "operating day" time period will produce the following relationship for the production run:

$$b_i = c_i + d_i Y \quad (5)$$

where:

$c_i$  = total fixed cost per production run for the  $i$  <sup>th</sup> product,<sup>2</sup>

$d_i$  = variable production run cost per unit of output for the  $i$  <sup>th</sup> product, and

$Y$  = hundredweight of powder produced during the production run.

An assumption is made at this point which specifies that the total annual powder production ( $Z$ ) will be divided evenly among the number of annual operating days ( $X$ ), i.e.,  $Y$  is a constant for each

<sup>1</sup>Relaxation of this assumption and its effects are considered later.

<sup>2</sup>These are costs that are fixed for a given production run if any output is to be produced. These "fixed" costs do not include items defined as a part of annual fixed costs. When viewed on an annual basis, these costs may be variable since the number of production runs is variable.

day of operation:<sup>1</sup>

$$Z = XY \quad (6)$$

where:

Z = annual powder production,

X = number of annual operating days, and

Y = hundredweight of powder produced during a production run.

By substituting equation (5) and (6) into equation (4), the total annual cost ( $TC_i$ ) relationship can now be restated:

$$\begin{aligned} TC_i &= a + (c_i + d_i Y)X \\ &= a + c_i X + d_i XY \\ &= a + c_i X + d_i Z \end{aligned} \quad (7)$$

Equation (7) provides the framework for the calculation of all costs stated in this study. Restated simply, equation (7) defines total annual costs to be the sum of annual fixed costs incurred with or without production, plus fixed costs for a production run incurred for each operating day but independent of volume of production, plus variable costs for a production run incurred as a consequence of processing operations and dependent upon volume of production.

Given values for the independent variables "X" and "Y", the total cost of a particular powder product produced over a period of a year will be determined by the values of "a", " $c_i$ ", and " $d_i$ "

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<sup>1</sup>Relaxation of this assumption and its effects are considered later.

which are to be developed by this study.<sup>1</sup> The values for these last three terms will be different for each of the various final products defined for consideration in this study and therefore will produce individual total cost figures.

The average total cost ( $ATC_i$ ) per hundredweight of a particular product can now be stated in terms of equation (7):

$$\begin{aligned} ATC_i &= \frac{TC_i}{Z} = \frac{a + c_i X + d_i Z}{Z} \\ &= \frac{a + c_i X}{Z} + d_i \end{aligned} \quad (8)$$

Equation (8) permits a direct statement of average cost per hundredweight of a particular powder product given the same values for the "X", "Y", "a", " $c_i$ ", and " $d_i$ " terms as for equation (7) above. It is therefore not necessary to perform the total cost calculation as a prerequisite for average cost calculation.

A mathematical model can also be presented for derivation of the "a", " $c_i$ ", and " $d_i$ " terms. The following mathematical definitions will describe the techniques applied in this study.

The mathematical expression used for the "a" term, representing total annual fixed cost for a particular final product, is as follows:

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<sup>1</sup>The range of the "X" and "Y" terms (number of operating days and daily production) are bounded, however, by certain limits of a technological nature. An upper limit is set for "X" by the maximum number of operating days contained in an annual time period. For any given level of annual production a lower limit is set for "X" by the maximum daily production capacity of the model plant, i.e.,  $Z/X \leq Y'$ , where  $Y'$  is the maximum daily production capacity.

$$a = \sum_i A_i \quad (9)$$

where:

$A_i$  =  $i^{\text{th}}$  annual fixed cost element,

$i = 1, 2, \dots, 6.$

For example, in this study the " $A_i$ " terms will be defined as follows:

$A_1$  = annual administrative expense,

$A_2$  = annual fixed labor expense,

$A_3$  = annual repairs and maintenance expense,

$A_4$  = annual depreciation expense,

$A_5$  = annual interest expense, and

$A_6$  = annual property tax expense.

Description of the mathematical expressions for the " $c_i$ " and " $d_i$ " terms will be made by reference to the definitions of "stages" and "phases" presented above and developed in the "definitions" section of Part III. The mathematical expression for the " $c_i$ " term, representing total fixed costs for a production run, is as follows:

$$c_i = \sum_{j=1}^n \sum_{k=1}^p \sum_{m=1}^q P_j \lambda_{jkm} \quad (10)$$

where:

$P_j$  = price of the  $j^{\text{th}}$  cost element,

$\lambda_{jkm}$  = total physical quantity of the  $j^{\text{th}}$  cost element used per production run in the  $m^{\text{th}}$  phase of the  $k^{\text{th}}$  stage,

$n = 17,$

$p = 6,$  and

$q = 5.$



The mathematical expression for the " $d_i$ " term, representing variable cost per unit of output for a production run, is as follows:

$$d_i = \sum_{j=1}^r \sum_{k=1}^s \sum_{m=6}^t P_j \lambda_{jkm} \quad (11)$$

where:

$P_j$  = price of the  $j^{\text{th}}$  cost element,

$\lambda_{jkm}$  = total physical quantity of the  $j^{\text{th}}$  cost element used per unit of product in the  $m^{\text{th}}$  phase of the  $k^{\text{th}}$  stage for a production run,

$r = 17$ ,

$s = 6$ , and

$t = 9$ .

All cost calculations will be made by reference to notations (7), (8), (9), (10), and (11). The specific application of these notations in this study can be further illustrated in the following manner. The " $\lambda_j$ " terms will be taken to be defined as follows:

- $j = 1$     Class A labor,
- 2        Class B labor,
- 3        Class C labor,
- 4        Electricity,
- 5        Natural gas,
- 6        Steam,
- 7        Water,
- 8        50 lb. plain bags,
- 9        100 lb. plain bags,
- 10       100 lb. government specification bags,
- 11       XY-12 chlorine,

- 12 LC-10 acid cleaner,
- 13 Shur-spray acid cleaner,
- 14 HC-90 alkali cleaner,
- 15 Felt roofing paper,
- 16 Malathion insecticide, and
- 17 1x4 pine lumber.

The cost element prices ( $P_j$ ) used in this study are presented in Appendix J and summarized in Table 57 of that section.

The "km" subscript notation for the " $\lambda_{jkm}$ " term which will be used in this study is summarized and presented in Table 1 of this section. It will be noticed that the "m" phases are not numbered consecutively from top to bottom in the first column of that table. The "fixed" phases of a production run occurred at the start and the finish of the production run time period. In order to facilitate presentation of the summation notation of (10) and (11) above, it was elected to number all of the "fixed" phases consecutively as they would occur during the production run. The intervening "variable" phases were then numbered consecutively as they would occur, starting with the next number after the last "fixed" phase number. The vertical arrangement of the phases within the table represents the normal order in which they would be expected to occur during the production run.

The application of summation notations (10) and (11) in this study can be illustrated further. Both notations indicate a triple summation of specific " $\lambda_{jkm}$ " elements which is to proceed in a particular sequence. The first of the three summations is make for a specific cost element (j) in a specific stage (k) over all phases

TABLE 1.--Mathematical model summation subscript notation for (k) stages and (m) phases<sup>a</sup>

Phases (m)	Stage I Evaporating (k=1)	Stage II Drying (k=2)	Stage III Bagging (k=3)	Stage IV Storage (k=4)	Stage V Truck ldg. (k=5)	Stage VI RR car ldg. (k=6)
m=1	Hookup	--	--	--	--	--
m=2	Vacuum buildup	Hookup	--	--	--	--
m=3	Warm-up	Warm-up	Warm-up	--	--	--
m=6	Operating	Operating	Operating	Operating	Operating	Operating
m=7	--	Shutting-down for downtime	Shutting-down for dryer maintenance	--	--	--
m=8	--	Downtime	Downtime	--	--	--
m=9	--	Warm-up after downtime	Warm-up after dryer downtime	--	--	--
m=4	Shutting-down	Shutting-down	Shutting-down	--	--	--
m=5	Cleanup	Cleanup	Cleanup	--	--	--

<sup>a</sup>Interpretation of the notation is as follows: "km" defines a phase within a stage of operation. For example, letting k = 1, and m = 1, indicates the hookup phase in the evaporating stage (stage 1). If k = 2, and m = 6, the operating phase of the drying stage (stage II) is indicated.



(m) that either are fixed or are variable for a production run (but not) both simultaneously). This first summation of notation (10) for phases that are fixed for a production run can be indicated by the following notation:

$$\sum_{m=1}^q \lambda_{jkm} \quad (12)$$

where:

$$j = 1, 2, \dots, 17;$$

$$k = 1, 2, \dots, 6; \text{ and}$$

$$q = 5.$$

This is the summation of physical "cost element requirements" in the specified phases, which are fixed for a production run, for specific cost elements (j) and stages (k).

For example, if  $j=1$ , and  $k=2$ , notation (12) would specify the total fixed class A labor ( $\lambda_1$ ) requirement for all fixed phases of the drying stage (stage II) in physical units. If  $j=7$ , and  $k=3$ , notation (12) would specify the total fixed water ( $\lambda_7$ ) requirement for all fixed phases of the bagging stage (stage III).

The first summation of notation (11) for phases that, in conjunction with other phases, are variable as a class for a production run can be indicated as follows:

$$\sum_{m=6}^t \lambda_{jkm} \quad (13)$$

where:

$$j = 1, 2, \dots, 17;$$

$$k = 1, 2, \dots, 6;$$

$$t = 9.$$

This is the summation of physical "cost element requirements" in the specified phases, which are variable for the production run, for specific cost elements (j) and stages (k).

This first summation is performed in this study in section I and II of Appendix H. The general procedure is illustrated in this section in Table 2 by the vertical summation of specific cost element requirements over all phases of each particular stage. It may be pointed out that the general presentation of Table 2 does not distinguish properly between the fixed phases ( $m = 1, 2, \dots, 5$ ) and the variable phases ( $m = 6, 7, 8, 9$ ) in its summation. This ambiguity will be clarified later.

It would be possible to perform the second summation of notations (10) and (11) with the " $\lambda_{jkm}$ " elements still in physical units. Since the summation would be over the stages for specific cost elements, no disparity of units would be encountered. However, for purposes of certain cost comparisons at a later stage, it was elected to apply the cost element prices at this point of the summation.<sup>1</sup> This step can be presented for both the fixed and variable phase summations of (12) and (13) as follows:

$$\sum_{m=1}^q P_j \lambda_{jkm} \quad (14)$$

where:

$j = 1, 2, \dots, 17;$

$k = 1, 2, \dots, 6;$

$q = 5;$  and

---

<sup>1</sup>The change from discussion of physical units to cost units in the literary descriptions will be denoted by use of the terms "cost element requirements" to indicate physical units and "cost element costs" to indicate cost units.

TABLE 2.--Illustrative use of the mathematical model first summation notation for aggregation of physical cost element quantities over all phases (m)

Phases (m)	Stage I Evaporating (k=1)	Stage II Drying (k=2)	• • •	Stage VI RR car loading (k=6)
m=1	$\lambda_{111}$ $\lambda_{211}$ $\vdots$ $\lambda_{(17)11}$	$\lambda_{121}$ $\lambda_{221}$ $\vdots$ $\lambda_{(17)21}$	$\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$	$\lambda_{161}$ $\lambda_{261}$ $\vdots$ $\lambda_{(17)61}$
m=2	$\lambda_{112}$ $\lambda_{212}$ $\vdots$ $\lambda_{(17)12}$	$\lambda_{122}$ $\lambda_{222}$ $\vdots$ $\lambda_{(17)22}$	$\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$	$\lambda_{162}$ $\lambda_{262}$ $\vdots$ $\lambda_{(17)62}$
$\cdot$ $\cdot$ $\cdot$	$\cdot$ $\cdot$ $\cdot$	$\cdot$ $\cdot$ $\cdot$		$\cdot$ $\cdot$ $\cdot$
m=9	$\lambda_{119}$ $\lambda_{219}$ $\vdots$ $\lambda_{(17)19}$	$\lambda_{129}$ $\lambda_{229}$ $\vdots$ $\lambda_{(17)29}$	$\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$	$\lambda_{169}$ $\lambda_{269}$ $\vdots$ $\lambda_{(17)69}$
First summation totals	$\sum_{m=1}^9 \lambda_{11m}$ $\sum_{m=1}^9 \lambda_{21m}$ $\vdots$ $\sum_{m=1}^9 \lambda_{(17)1m}$	$\sum_{m=1}^9 \lambda_{12m}$ $\sum_{m=1}^9 \lambda_{22m}$ $\vdots$ $\sum_{m=1}^9 \lambda_{(17)2m}$	$\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$ $\cdot \cdot \cdot$	$\sum_{m=1}^9 \lambda_{16m}$ $\sum_{m=1}^9 \lambda_{26m}$ $\vdots$ $\sum_{m=1}^9 \lambda_{(17)6m}$



$$\sum_{m=6}^t P_j^{\lambda} j_{km} \quad (15)$$

where:

$$j = 1, 2, \dots, 17;$$

$$k = 1, 2, \dots, 6;$$

$$t = 9.$$

This step is incorporated in the initial presentation of the cost element stage totals in Table 3.

The second summation can now be made for specific cost element costs over all of the stage totals obtained by the first summations. This step can be indicated for the fixed phases by the following notation:

$$\sum_{k=1}^p \sum_{m=1}^q P_j^{\lambda} j_{km} \quad (16)$$

where:

$$j = 1, 2, \dots, 17;$$

$$p = 6;$$

$$q = 5.$$

For the variable phases this second summation notation can be indicated as follows:

$$\sum_{k=1}^s \sum_{m=6}^t P_j^{\lambda} j_{km} \quad (17)$$

where:

$$j = 1, 2, \dots, 17;$$

$$s = 6;$$

$$t = 9.$$

This second summation is indicated in Table 3 by the lateral

TABLE 3.--Illustrative use of the mathematical model second and third summation notations for aggregation of cost element costs over all stages (k) and all cost elements (j)

Cost elements (j)	First summation stage totals with prices applied				Second summation cost element totals
	Stage I Evaporating (k=1)	Stage II Drying (k=2)	...	Stage VI RR car loading (k=6)	
j=1	$\sum_{m=1}^9 P_1^{\lambda} 11m$	$\sum_{m=1}^9 P_1^{\lambda} 12m$	...	$\sum_{m=1}^9 P_1^{\lambda} 16m$	$\sum_{k=1}^6 \sum_{m=1}^9 P_1^{\lambda} 1km$
j=2	$\sum_{m=1}^9 P_2^{\lambda} 21m$	$\sum_{m=1}^9 P_2^{\lambda} 22m$	...	$\sum_{m=1}^9 P_2^{\lambda} 26m$	$\sum_{k=1}^6 \sum_{m=1}^9 P_2^{\lambda} 2km$
...	...	...		...	...
j=17	$\sum_{m=1}^9 P_{(17)}^{\lambda} (17)1m$	$\sum_{m=1}^9 P_{(17)}^{\lambda} (17)2m$	...	$\sum_{m=1}^9 P_{(17)}^{\lambda} (17)6m$	$\sum_{k=1}^6 \sum_{m=1}^9 P_{(17)}^{\lambda} (17)km$
Third summation grand total cost					$\sum_{j=1}^{17} \sum_{k=1}^6 \sum_{m=1}^9 P_j^{\lambda} jkm$

summation of the column stage totals from Table 2. The general presentation of this table does not distinguish between either the fixed and variable phases, or between variations in processing techniques accomplished by the exclusion of either stage V or stage VI.

The third summation for the fixed and variable phases is then equivalent to the summation notation originally presented as notations (10) and (11) of this section. This third summation is indicated in Table 3 by the vertical summation of all cost element costs. This general presentation is again subject to the same subscript notation limitations as indicated above.

It yet remains to remove the ambiguities that have been indicated to be imposed by the general summation notations presented in Tables 2 and 3. This can be done by specifying the exact summation subscript notations required for the " $c_i$ " and " $d_i$ " terms of each final product considered by this study. This step is summarized and presented in Table 4.

The mathematical notation for presentation of costs in this mathematical model has been specific for particular final products during an annual time period and has assumed equal distribution of annual production over each of the processing days. It would be necessary to require the model plant to produce a single product for an entire annual time period with daily production runs of equal duration in order to coincide with the assumptions of the mathematical model. Implications of these assumptions and techniques for their relaxation are considered briefly in Part V with the presentation of total and average processing costs for the model plant.



TABLE 4.--Summary of the mathematical model triple summation "jkm" subscript notations for the " $c_i$ " and " $d_i$ " terms of all six types of processing associated with distinct final products

Final product <sup>a</sup> processing	Notation for " $c_i$ " terms	Notation for " $d_i$ " terms
Truck loading		
50-lb. plain bags	$j = 1, 2, \dots, 8, 11, \dots, 17$ $k = 1, 2, \dots, 5$ $m = 1, 2, \dots, 5$	$j = 1, 2, \dots, 8, 11, \dots, 17$ $k = 1, 2, \dots, 5$ $m = 6, 7, 8, 9$
100-lb. plain bags	$j = 1, 2, \dots, 7, 9, 11, \dots, 17$ $k = 1, 2, \dots, 5$ $m = 1, 2, \dots, 5$	$j = 1, 2, \dots, 7, 9, 11, \dots, 17$ $k = 1, 2, \dots, 5$ $m = 6, 7, 8, 9$
100-lb. gov't bags	$j = 1, 2, \dots, 7, 10, \dots, 17$ $k = 1, 2, \dots, 5$ $m = 1, 2, \dots, 5$	$j = 1, 2, \dots, 7, 10, \dots, 17$ $k = 1, 2, \dots, 5$ $m = 6, 7, 8, 9,$
RR car loading		
50-lb. plain bags	$j = 1, 2, \dots, 8, 11, \dots, 17$ $k = 1, 2, 3, 4, 6$ $m = 1, 2, \dots, 5$	$j = 1, 2, \dots, 8, 11, \dots, 17$ $k = 1, 2, 3, 4, 6$ $m = 6, 7, 8, 9$
100-lb. plain bags	$j = 1, 2, \dots, 7, 9, 11, \dots, 17$ $k = 1, 2, 3, 4, 6$ $m = 1, 2, \dots, 5$	$j = 1, 2, \dots, 7, 9, 11, \dots, 17$ $k = 1, 2, 3, 4, 6$ $m = 6, 7, 8, 9$
100-lb. gov't bags	$j = 1, 2, \dots, 7, 10, \dots, 17$ $k = 1, 2, 3, 4, 6$ $m = 1, 2, \dots, 5$	$j = 1, 2, \dots, 7, 10, \dots, 17$ $k = 1, 2, 3, 4, 6$ $m = 6, 7, 8, 9$

<sup>a</sup>These six types of "final products" can be produced during either five-day or six-day weeks (see Table 8 in Part III).

### III. ANALYSIS OF THE DRYING PROCESS

The initial approach to analysis of the milk drying processing costs was a study of a sample plant. A careful inventory was made of plant equipment and a detailed description of the product flow was developed. A list of final products was compiled and a detailed description was made of variations in product flow associated with differentiation of final products.

These detailed descriptions permitted development of a set of definitions to be used in further analysis of the case study plant. The presentation of descriptions and definitions will be reversed in the section to follow, however. First, a set of definitions will be developed with the descriptions of plant technology and operations following.

#### Definitions and Terminology

A manageable presentation of the descriptions of the various plant operations requires development of a framework of definitions and standard terminology as a point of reference. In general, these definitions will fall into two general categories. Definitions concerned with specification of time period limits will be presented under the heading of "time period definitions." Definitions that were developed to aid in the analysis of the product flow are presented under the "product flow definitions" heading.

#### Time period definitions

Three distinctly different time periods were associated with the analysis of costs for the model plant. These three time periods may be

specified as follows: (1) a production year, (2) a production week, and (3) a production day. Definitions for two of these time periods were derived from "linearity" specifications of the mathematical model employed in Part II. The third time period definition resulted from an attempt to incorporate into the analysis a certain degree of the time observed to be lost during breakdowns of the dryer during processing operations.

Production year.--This time period was defined to include a twelve calendar-month period convenient for accounting purposes. This twelve month period was considered to be composed of fifty-two production weeks or a total of either 260 or 312 production days (depending upon the following "production week" definitions). This definition was useful in allocation of annual fixed costs such as administrative expenses, fixed labor, repairs and maintenance, depreciation, interest, and property taxes. This definition was therefore associated with the linearity specifications of the mathematical model.

Production week.--This time period was defined to include any seven calendar-day period and to consist of a maximum of either five or six production days. The six-day production week was intended to be representative of regular Monday through Saturday processing operations. The five-day production week definition was developed in Appendix G and was intended to represent processing operations in which one day during the week was allocated to a period of preventive maintenance for the dryer equipment. This restriction left a remainder of only approximately five processing days in a week. This definition was useful in specifying variations in quantities of downtime observed during processing in the two types of "production week" definitions.



Production run.--A twenty-four hour definition was specified for the production run time period in this study. It was defined to include all activities normally occurring during a day of processing in the case study plant. The production run is composed specifically of pre-processing activities to prepare the equipment, processing activities to operate the equipment, and post-processing activities to dismantle and clean the equipment. The production run therefore consists of a complete processing cycle including activity required to put the processing equipment into operation and to return it to a state of readiness for subsequent processing.

This time period was also associated with the linearity specifications of the mathematical model. The pre-processing and the post-processing periods of the production run were essentially fixed in duration for any individual cycle of plant activity. The length of the processing period, however, was varied in proportion to the quantity of product desired. These two types of periods within the production run definition therefore satisfied the definitions for the "fixed" and "variable" terms of the mathematical model. A more complete description of the production run and its subdivisions is presented in Appendix C.

#### Product flow definitions

Product flow definitions were developed as a matter of convenience in the analysis and presentation of this study. These definitions abstract from observed operations in the case study plant by application of methods of logic and individual definitions do not necessarily find a parallel in common plant terminology.

These definitions were useful in the specification of product flow subdivisions for further analysis and description. Five general types of

definitions will be covered in this section. These will include definitions for production processes, decision points, processing stages, production run phases and cost elements. Figure 1 illustrates application of some of these definitions to the analysis of this study.

Production processes.--The product flow of the entire plant can be subdivided and classified according to the general type of final product being processed. These subdivisions can be denoted as "production processes" and specific equipment can be defined for each "process." Examples of processes in a plant might be such activities as the butter process, the dry milk process, the grade A bottled milk process, etc.

Some equipment may serve more than one specific process, however, either simultaneously or at different times. Equipment selected as relevant to the study of the case study plant dry milk process was such that all items could conveniently be treated as processing only final dry milk products. This equipment which was defined to be associated with the dry milk process included the items required for the evaporating, drying, bagging, storage, and loading of powder for transportation operations in the plant. A complete inventory of the dry milk process equipment can be found in Appendix A.

Decision points.--Further analytical subdivision of the dry milk process involved location and identification of certain "decision points." These points were generally characterized by an identifiable production or selling alternative at the point in question. Two types of alternatives will be considered.

Product alternatives.--These decision points were of two types. Alternatives for changes in the operating conditions of particular equipment units within a given processing stage (such as the "evaporating

TIME (hrs)	STAGE I	STAGE II	STAGE III	ACTIVITY
1	HOOK UP PHASE			PREPA- RATION
2				
3				
	VACUUM BUILDUP			
	WARM-UP	hookup WARM-UP	WARM-UP	
4	OPERATING	OPERATING	OPERATING	PROCESS- ING
<hr/>				
15	PHASE (12.4167hrs. max.)	PHASE	PHASE	
	SHUTTING- DOWN	shutting-down	shutting-down	
16			CLEANUP	
17	CLEANUP PHASE	CLEANUP PHASE		POST PROCESS- ING
18				
19				
20				
<hr/>				
23				
24				

Fig. 1.--Relationship between production run phases and elapsed time during a production run for the evaporating, drying, and bagging stages of the model plant.



stage"), were identified for certain types of product differentiation.<sup>1</sup> Alternatives between items of equipment were identified for other types of product differentiation. For example, variations in the temperature of milk leaving the live steam heater affected the heat classification of the powder, and variations in the types of screens used in the sifter determined whether powder particles that could be classified as "instant" were separated for sale as such or were combined for sale as regular dry milk. In comparison, condensed milk from the evaporator could either be dried in the drying equipment or alternatively could be cooled in the cooling plate and be sold as bulk condensed milk. Both of these types of product alternative decision points were useful in description of the product flow in Appendix B, and in specification of exact cost element requirements for each final product in Appendix H.

Production run alternatives.--These decision points were usually marked by completion of some identifiable production run function or activity such as hookup of equipment, cleaning of equipment, etc. An alternative is presented at these points for either continuation of the production run or for suspending further production run progress in lieu of some other temporary activity. As an illustrative example, at the start of the processing period, equipment is in complete readiness for processing but can be held at this point for a period of time without actual initiation of processing.

These points were useful in identification of the "production run phases" and usually involved a marked change in production run cost element requirements. This facilitated calculation of the cost element requirements in Appendix H.

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<sup>1</sup>A "processing stage" will be defined later in this section.

Processing stages.---A technical definition for a "stage" has been developed by Brems as "the aggregate of all units of a single durable factor employed by a plant (with or without nondurable factors cooperating with it)."<sup>1</sup> Another definition has been given by French, Sammet, and Bressler in an amplification of the Brems' definition:

A somewhat broader definition [of a stage] might include several different but closely cooperating types of durable factors within a single stage and would also take account of the fact that some stages might consist entirely of variable factors. Thus, a stage consists of all productive services--durable or nondurable--that cooperate in performing a single operation or a group of minor but closely related operations.<sup>2</sup>

Six different stages were defined for the dry milk process for the purposes of this study. These six stages included the evaporating stage, drying stage, bagging stage, storage stage, truck loading stage, and railroad car loading stage. The first four stages were associated with units of durable factors while the last two stages were principally associated with units of nondurable factors. A complete definition and description of each stage is presented in Appendix B.

Production run phases.---The definition developed previously for the "production run alternatives" can be used for further subdivision of the production run beyond the pre-processing, processing, and post-processing categories of the production run identified initially. These additional subdivisions were denoted as individual "production run phases" within the definition of each processing stage. These phases can perhaps be described loosely as "related and identifiable production run activity contained within a given processing stage."

<sup>1</sup>Hans Brems, "A Discontinuous Cost Function," American Economic Review, XLII (September, 1952), p. 577.

<sup>2</sup>Ibid., 545.



Boundaries of the phases were marked either by pronounced changes in the cost element requirements or by the completion of an identifiable work activity. The usefulness of the "phase" concept centered principally upon coincidence of the phase boundaries with changes in cost element requirements. Cost element requirement calculations for Appendix H were considerably facilitated by this concept.

Certain production run phases (such as "processing" and "shutting-down") showed similarities to phases of other stages in their general location in the production run and duration. Other phases (such as "hookup of equipment" in the evaporating stage) were unique for a particular stage. The production run phases for the first three stages were presented in Figure 1 to illustrate the relationship between the phases during progress of the production run. Phases for the remaining three stages are not indicated in the illustration because they did not have the same type of direct relationship to the production run. The "loading" stages were separated from regular processing by the "storage" stage and occurred only at spaced intervals of plant processing and were not concurrent with each production run. A complete definition and description of each production run phase is presented in Appendix C.

Cost elements.--Each processing cost can be expressed in terms of a specific number of units of a particular resource and a given price for that resource. The individual resources contributing to processing costs were referred to as "cost elements" in this study. A total of seventeen different cost elements were identified for measurement and calculation in this study. The individual cost elements were as follows: class A labor, class B labor, class C labor, electricity, natural gas, steam, water, fifty-pound unmarked (or plain) powder bags, hundred-pound plain bags, hundred-pound government specification bags, XY-12 chlorine,



LC-10 acid cleaner, HC-90 alkali cleaner, felt roofing paper, malathion insecticide, and one-by-four pine bracing lumber.

### Plant Technology and Operations

Description of plant operations will follow in the remainder of Part III and will be a combination of description for the case study plant and modifications made for use with the model plant. Indication will be given at points at which the description of the model plant operations departs appreciably from the actual situations existing in the case study plant.

Description will begin with plant technology and operations and will proceed to summaries of the plant product flow, processing stages, and production run phases. A description of specifications for final products will be made for reference in the presentation of processing costs in Part V. Part III will be concluded with a set of simplifying technological assumptions that have been incorporated into the model plant operations for the analysis in this study.

### Components of the plant

Physical description of the plant facility components can be subdivided into roughly four different categories: permanent building, evaporator, dryer, and bagging equipment. This arbitrary classification is used for convenience in the following presentation and will not have significance beyond this section.

#### Permanent building

The building selected for the model plant is a brick and concrete structure with dimensions ninety-by-ninety feet and a total floor space of approximately 8,199 square feet. This is an abstraction from the

building in use by the case study plant. The model plant building represents a consolidation of the various areas which are dispersed over a larger area in the case study plant. Figure 2 illustrates the principal areas and equipment locations in the model plant building.

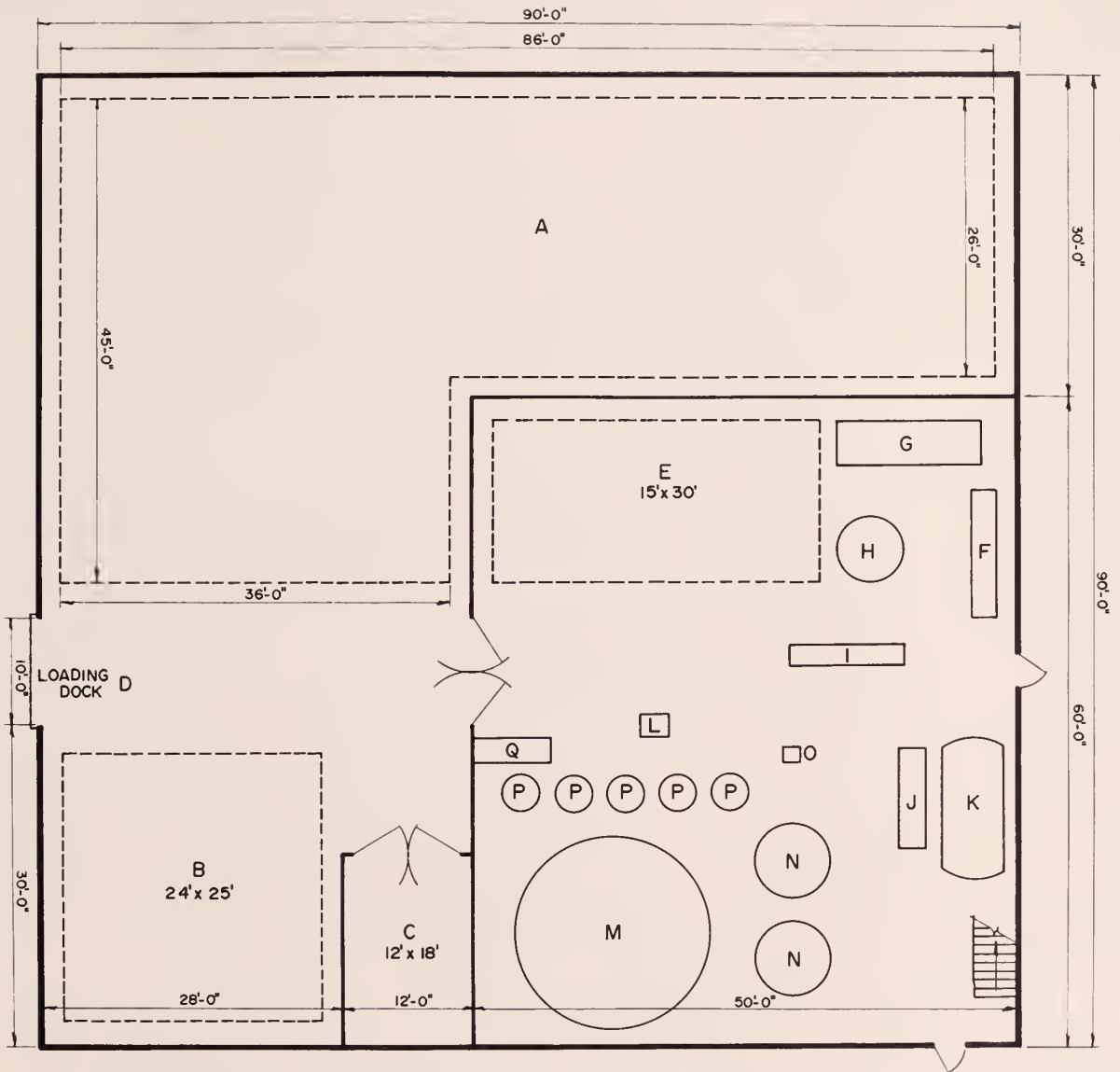
Storage areas.---These two areas have fifteen foot ceilings, a total of approximately 4,136 square feet of floor space and provide for storage of powder containers in two different locations. The larger storage section has a total floor space of 3,380 square feet and the smaller section has a total area of 756 square feet. After allowance for an airspace two feet wide along all walls a combined net storage area of approximately 3,376 square feet remains. A concrete floor, cinder block or brick walls, and plaster ceiling were specified for this area.

The quantity of powder which can be stored in this space depends upon whether the powder has been placed in fifty-pound bags or hundred-pound bags. Pallets loaded with bags can be stacked two-high when loaded with either fifty-pound or hundred-pound bags. Dimensions of the pallets when loaded are different for each of the two bag sizes, however. The volume of dry powder that can be stored per square foot of floor space is therefore different for each of the two bag sizes.

Storage capacity of the model plant storage areas was calculated for fifty-pound powder bags in the following manner. Floor space occupied by a pallet loaded with fifty-pound bags is equal to:

$$\begin{aligned} 44 \text{ in.} \times 59 \text{ in.} &= 2,596 \text{ sq. in.} \\ &= 18.03 \text{ sq. ft.} \end{aligned}$$

A loaded pallet contains 36 fifty-pound bags or a total of 1,800 pounds of powder. Pallets stacked two-high would total 3,600 pounds in this 18.03 square feet area or approximately 199.67 pounds per square feet.



- A. Large storage area
- B. Small storage area
- C. Bagging room
- D. Loading area and dock
- E. Evaporator
- F. Grade A holding tube
- G. Live steam heater
- H. Hot well

- I. Evaporator control panel
- J. Cooling plate
- K. Insulated storage vat
- L. Dryer high pressure pump
- M. Drying chamber
- N. Powder-air separators
- P. Powder collectors
- Q. Dryer control panel

Fig. 2.--Hypothetical model plant floor plan and equipment location.



This would indicate adequate storage space for approximately 674,086 pounds of powder or approximately 13,482 fifty-pound bags. With thirty-six bags to a pallet, this would represent a requirement of approximately three hundred seventy-five pallets in order to be able to fill the storage area. This is roughly twenty-two semi-trailer truckloads at 31,000 pounds each or eight and one-half railroad carloads at 80,000 pounds each.

Storage capacity for hundred-pound bags can be calculated similarly. Floor space occupied by a pallet loaded with hundred-pound bags is equal to:

$$40 \text{ in.} \times 57 \text{ in.} = 2,280 \text{ sq. in.}$$

$$= 15.83 \text{ sq. ft.}$$

A loaded pallet contains 15 hundred-pound bags or a total of 1,500 pounds of powder. Pallets stacked two-high would total 3,000 pounds in this 15.83 square feet area or approximately 189.51 pounds per square foot. This would indicate adequate storage space for approximately 639,786 pounds of powder or approximately 6,398 hundred-pound bags. Fifteen bags to a pallet would represent a requirement of approximately four hundred twenty-seven pallets in order to fill the storage area. This is roughly twenty semi-trailer truckloads at 31,000 pounds each or eight railroad carloads at 80,000 pounds each.

Bagging area.--This room has an eight-foot ceiling and approximately 216 square feet of floor space. A concrete floor, plastered ceiling and tiled walls were specified. Three bagging spouts equipped with two-way valves entered from overhead at one end of the room.

Other equipment located in this room includes a platform scale (93), a sewing machine (94), a moisture balance tester (95), and an

electric clock with sweep-second hand. Two men were assigned to this area for bagging powder in hundred-pound bags and three men for fifty-pound bags.

Evaporating and drying area.--This area has a twenty-five foot ceiling and approximately 3,600 square feet of floor space. Concrete floors, plastered ceilings and tiled walls were specified.

Located in this area is an insulated storage vat, all of the equipment associated with the Rogers evaporator and a majority of the equipment associated with the Coulter spray dryer. The remainder of the dryer equipment (such as intake and exhaust fans, transfer fan, air filters, burner fan and the gas burner) are located on the second floor above this area.

The top part of the drying chamber for the Coulter dryer extends above the roof and is accessible by a small, circular staircase beside the drying chamber. Sides of the drying chamber are insulated against heat loss and the top is enclosed to provide a space for maintenance access.

Loading dock.--Provision is made at one side of the storage space area for a truck loading dock ten feet wide. All powder is loaded upon trucks at this point. When shipment by rail is desired, powder containers must first be loaded into a truck for transfer to a railroad loading ramp where it is reloaded into a railroad car.

#### Evaporator

The second category of the model plant's components to be discussed will be the evaporator and its associated equipment. The evaporator in use at the case study plant was the result of a number of different conversions over an extended period of time. The evolution



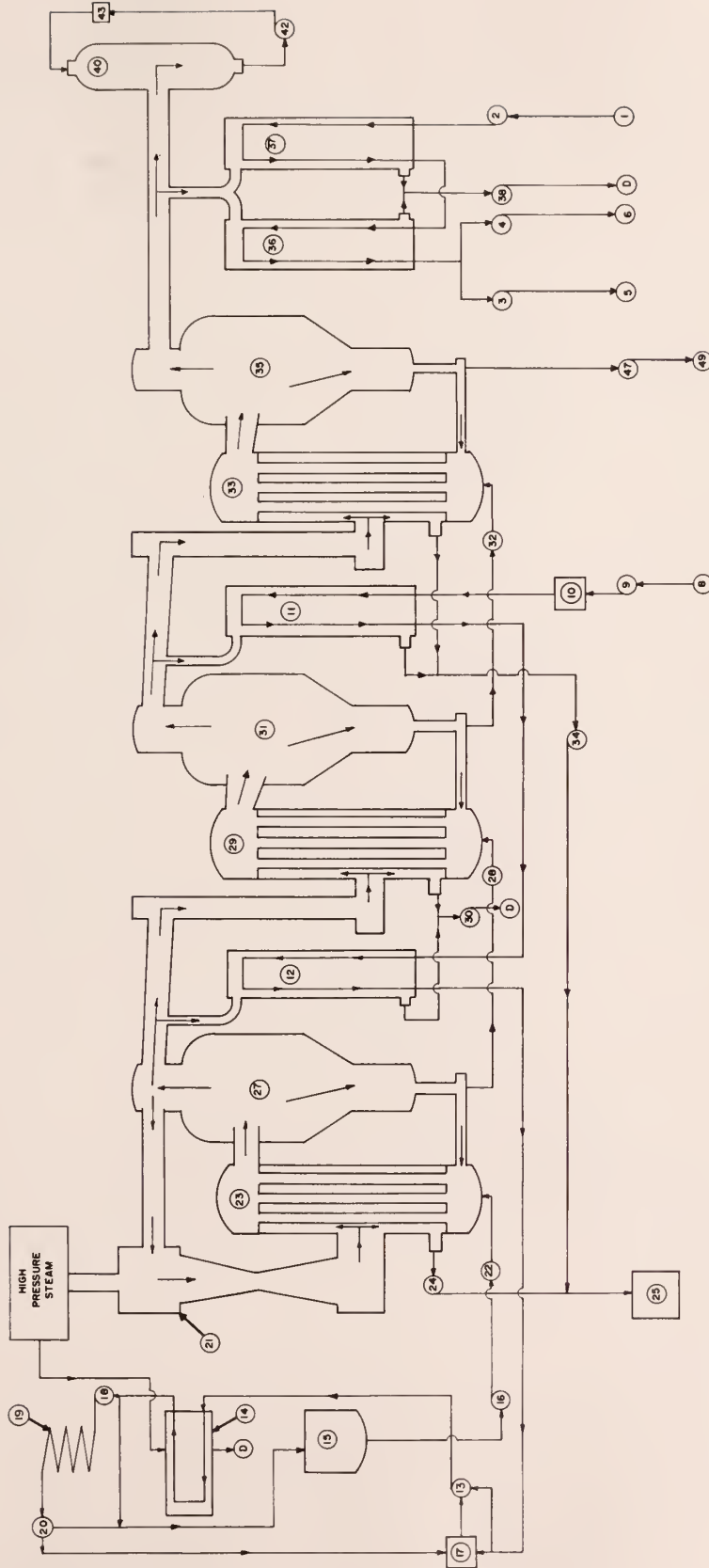
began with a single-effect vacuum pan which was converted into a double-effect with the original pan as the first effect. Later the pan was discarded and the unit was converted into a higher capacity, tubular, double-effect. In turn one of these effects was discarded and the unit converted into a higher capacity, thermo-compression, double-effect. Finally, with the discarding of one of these effects and the addition of two new effects the present triple-effect unit was completed. Figure 3 is a schematic of the evaporator installation.

The evaporator unit, as it had reached its present stage of evolution, was a Rogers triple-effect unit equipped with thermo-compressor, vapor and interstage heaters, liquid level flow valves, turbidity detector and condensate reservoir. The unit was rated for a capacity of 40,000 pounds of milk per hour with incoming milk at 100° F. and 8.75 percent solids not fat (SNF). This will result in 7,960 pounds of condensed product per hour at 90° F. and 44.0 percent SNF. Reference to Table 44 of Appendix E indicates that the average processing rate for the two-year period for which records were studied was 39,091 pounds of skim milk per hour.

The unit required 8,812 pounds of steam per hour at 180° F. and 100 pounds per square inch gauge according to engineering specifications. Table 6 presents a summary of the steam requirements and fluid temperatures for the Rogers unit.

The steam requirement can be expressed as approximately 220 pounds steam per thousand pounds of milk input. For the rated 40,000 pounds per hour this would result in an hourly steam requirement of approximately 8,800 pounds. The water requirement that must be handled by the counter-current condensor can likewise be expressed as 11.3





D. Condensate to drain.

Fig. 3.---Flow diagram for the Rogers triple-effect evaporator selected for the model plant evaporating stage.

TABLE 5.--Identification of evaporator equipment presented in Figure 3

Key	Item	Key	Item
1.	Whole milk storage vat	24.	1st-effect chest condensate pump and motor
2.	Vapor heater milk supply pump and motor	25.	Condensate reservoir
3.	Cream separator milk transfer pump and motor no. 1	27.	1st-effect separator
4.	Cream separator milk transfer pump and motor no. 2	28.	2nd-effect liquid level valve
5.	Cream separator no. 1	29.	2nd-effect chest
6.	Cream separator no. 2	30.	2nd-effect chest and 1st-effect interstage heater condensate pump and motor
8.	Skim milk storage vat	31.	2nd-effect separator
9.	Evaporator milk supply pump and motor	32.	3rd-effect liquid level valve
10.	Evaporator input flow meter	33.	3rd-effect chest
11.	2nd-effect interstage heater	34.	3rd-effect chest and 2nd-effect interstage heater condensate pump and motor
12.	1st-effect interstage heater	35.	3rd-effect separator
13.	Live steam heater pump and motor	36.	3rd-effect vapor heater no. 1
14.	Live steam heater	37.	3rd-effect vapor heater no. 2
15.	Hot well	38.	3rd-effect vapor heaters condensate pump and motor
16.	Hot-well pump and motor	40.	Counter-current condenser
17.	Grade A surge tank	42.	Condensor pump and motor
18.	Holding tube pump and motor	43.	Cooling tower no. 1 (large)
19.	Grade A holding tube	47.	Product removal pump and motor
20.	Flow-diversion valve	49.	Condensed milk storage vat
21.	Thermo-compressor		
22.	1st-effect liquid level valve		
23.	1st-effect chest		

TABLE 6.--Steam requirements for Rogers triple-effect evaporator<sup>a</sup>

Unit	Milk temperature		Steam required (lbs./hr.)
	In	Out	
Vapor heaters . . . . .	40° F.	100° F.	Reused
Interstage heaters . . . . .	100° F.	145° F.	Reused
Live steam heater . . . . .	145° F.	168° F.	920
Steam ejectors . . . . .	--	--	367
Thermo-compressor . . . . .	--	--	7,525
Total steam required per hour			8,812

<sup>a</sup>Rogers Flow Sheet No. 3, dated 9-18-61.

gallons per minute per thousand pounds of milk input or a total of 452 gallons per minute.

The evaporator requires an area approximately fifteen feet wide by thirty feet long for a total floor space of 450 square feet. The overall height was in excess of twenty feet. In addition to the evaporating unit itself, there was also other equipment located in this area which was indirectly associated with the evaporator. This included a combination of holding tube, flow diversion valve and twenty-five gallon surge tank for grade A processing; a chilled water cooling plate; and a 5,000 gallon insulated storage vat. A complete inventory of evaporating equipment is presented in Table 38 of Appendix A.

#### Dryer

The case study plant dryer unit was a Coulter spray dryer installed by the Food Equipment Corporation. Figure 4 is a schematic of the dryer installation. The Coulter spray dryer was rated at 3,500 pounds of powder per hour when spraying forty-five percent solids evaporated milk.



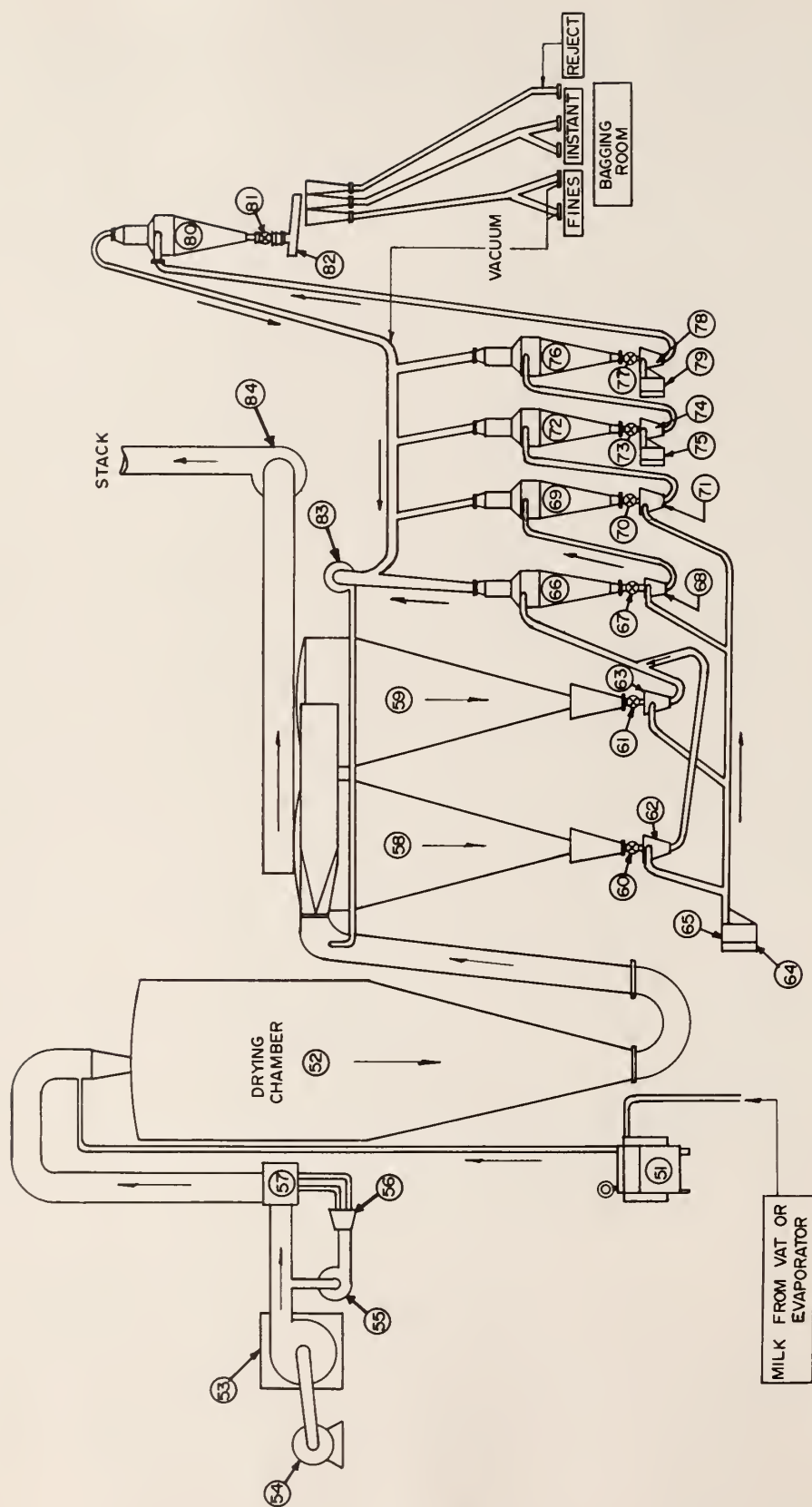


Fig. 4.--Flow diagram for the Coulter spray dryer selected for the model plant drying stage.

TABLE 7.--Identification of dryer equipment presented in Figure 4

Key	Item	Key	Item
51.	Dryer high-pressure feed pump and motor	69.	Powder collector no. 2
52.	Drying chamber	70.	Airlock and motor no. 4
53.	Air intake filter	71.	Powder redrier no. 4
54.	Air intake fan and motor	72.	Powder collector no. 3
55.	Gas burner fan and motor	73.	Airlock and motor no. 5
56.	Gas-air jets	74.	Powder cooler no. 1
57.	Gas burner	75.	Powder cooler no. 1 air filter
58.	Powder-air separator no. 1	76.	Powder collector no. 4
59.	Powder-air separator no. 2	77.	Airlock and motor no. 6
60.	Airlock and motor no. 1	78.	Powder cooler no. 2
61.	Airlock and motor no. 2	79.	Powder cooler no. 2 air filter
62.	Powder redrier no. 1	80.	Powder collector no. 5
63.	Powder redrier no. 2	81.	Airlock and motor no. 7
64.	Redrier air heater intake filter	82.	Cyclocentric powder sifter and motor
65.	Redrier air heater	83.	Transfer fan and motor
66.	Powder collector no. 1	84.	Exhaust fan and motor
67.	Airlock and motor no. 3		
68.	Powder redrier no. 3		

Reference to Table 46, Appendix E, indicates that during the two-year period for which data were available, the dryer had averaged 3,482 pounds of powder per processing hour.

Equipment associated with the dryer was a Manton Gaulin high-pressure feed pump delivering condensed milk to the drying chamber at

a pressure of about 3,500 to 4,000 pounds per square inch, and a Ro-ball, cyclocentric sifter for handling dry powder. Space allocated to the dryer and associated equipment on the ground floor was an area about thirty by thirty-five feet or a total of approximately 1,050 square feet. Additional dryer equipment was located on the second floor above this area as was indicated in the previous section describing the "permanent building."

This model of the Coulter spray dryer has been the largest capacity model produced by the Food Equipment Corporation until quite recently. The largest capacity model currently designed is a unit rated at 5,500 pounds of powder per hour.<sup>1</sup> Interviews with plant personnel of the case study plant indicated that the existing unit was thought to probably be capable of a sustained rate of production ten to fifteen percent greater than the present rate of production. This dryer was not being pushed to its full potential because it was run directly from the evaporator and therefore was limited to the output of the evaporator.

Another Coulter spray dryer rated at 3,500 pounds of powder per hour has been reported to have an average production of approximately 4,250 pounds of powder per hour. Part of this higher capacity has been attributed to the fact that the installation was spraying a higher concentration of condensed milk.<sup>2</sup>

#### Bagging equipment

Equipment associated with the bagging operation included a 250 pound platform scale with a dial indicator marked in one-quarter pound

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<sup>1</sup>Letter from Wm. E. Hoyt, Chief Engineer, Food Equipment Corporation, Rockford, Illinois, April 9, 1964.

<sup>2</sup>Ibid.



graduations, a bag-closing sewing machine suspended over the platform scales, a moisture balance tester for checking the moisture content of the powder, a stencil cutting machine and stencil brush, an electric forklift truck and battery recharger, and six hundred wooden pallets for storing the bagged powder.

#### Summary of product flow

When the plant is in operation and the powdered milk process is actually processing, the flow of incoming milk and its subsequent product forms can be traced through the equipment described above. An understanding of this product flow is central to an accurate calculation of cost element requirements. The product flow of the model plant will be summarized and presented as the basis for the further description of processing stages and phases.<sup>1</sup> Figure 5 presents a flow diagram of the product flow for the case study plant.

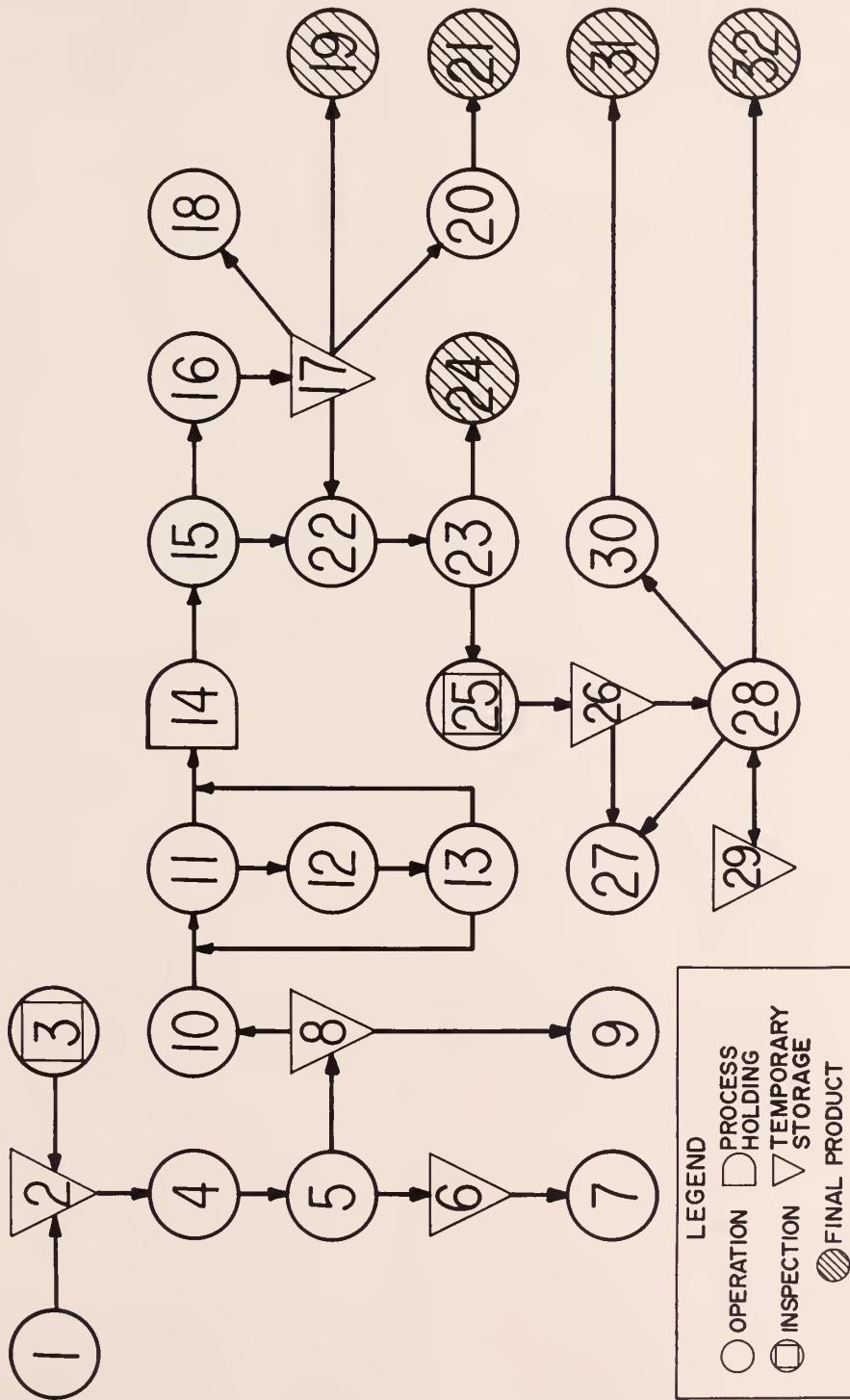
1. Incoming milk is heated from 40° F. to 100° F. by vapor from the third effect in the evaporator vapor heaters before going to the cream separators and from there to temporary storage vats.
2. Skim milk from the storage vats is then heated from 100° F. to 145° F. by vapor from the first and second effects in the evaporator interstage heaters and again from 145° F. to 168° F. in the live steam heater before going to the hot well.  
(During grade A processing a holding tube, flow diversion valve and surge tank are introduced into the product flow after the live steam heater.)
3. After a short holding time in the hot well, skim milk at 162° F. is pumped to the first effect of the evaporator. Condensed

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<sup>1</sup>A more detailed description of the product flow can be found in Appendix B.

Fig. 5.--General product flow for activities related to the model plant drying process.

1. Bulk tank truck receiving	12. Holding tube (grade A)	23. Sifting
2. Whole milk storage vat	13. Flow diversion valve	24. Reject powder
3. Can truck receiving	14. Hot well holding	25. Bagging
4. Evaporator vapor heating	15. Evaporating	26. Stacking
5. Cream separating	16. Cooling plate	27. In-plant powder transfer
6. Cream storage vats	17. Condensed milk storage vat	28. Truck loading
7. In-plant cream transfer	18. In-plant condensed transfer	29. Warehouse storage
8. Skim storage vat	19. Bulk truck condensed sales	30. Railroad car loading
9. In-plant skim transfer	20. Ten-gallon can filling	31. Railroad car powder sales
10. Evaporator interstage heating	21. Ten-gallon can cond. sales	32. Truck powder sales
11. Live steam heater	22. Drying	





product is subsequently removed from the third effect at a temperature of approximately 110° F. and a concentration of 43 percent solids.

4. Condensed product from the evaporator is raised to pressures from 3,000 to 4,000 pounds per square inch by the dryer high pressure feed pump and introduced into the drying chamber.
5. Hot air introduced into the drying chamber from around the spray nozzles evaporates the moisture from the spray droplets before they reach the bottom of the chamber. Although incoming air is approximately 475° F., a combination of evaporation and rapid expansion from the high pressures prevents scorching of the powder particles.
6. The dry powder is sifted, bagged, tested for moisture content, weighed, sealed and placed upon wooden pallets in the bagging room.
7. The electric forklift removes the pallets from the bagging room and places them in temporary storage until shipment.
8. Pallets are removed from temporary storage with the forklift and taken to the loading dock for shipment. If delivery is to be made by truck, bags are removed from the pallets and stacked in the truck by hand. If delivery is to be made by railroad car, the pallets are loaded into a truck for transfer to a railroad loading dock nearby. The bags are then removed from the pallets and stacked into the railroad car by hand.

#### Summary of processing stages

Application of the definition for "processing stages" developed at the first of Part III will be made to the milk drying process in this

section. This will permit subdivision of the product flow for convenience in the data collection of Part IV.

The more broad definition of the French, Sammet, and Bressler study was adopted for use. The pertinent definition may be quoted again at this point for reference: ". . . a stage consists of all productive services--durable or nondurable--that cooperate in performing a single operation or a group of minor but closely related operations."<sup>1</sup> The various operations and equipment were subdivided into six different stages which will be individually described. A description of the complete product flow occurring within these stages can be found in Appendix B.

Stage I: Evaporating.--This stage included all equipment associated with the evaporating operation of the model plant. Items in addition to the evaporator included the live steam heater, the holding tube and its associated equipment, the hot well, and all of the various pumps, motors, fans and flow meters that are customarily associated with the operation of an evaporator. The processing operation of this stage included all activities from the point at which warm skim milk at about 100° F. was removed from the temporary storage vats and pumped to the evaporator interstage heaters until the point at which the condensed product was removed from the final evaporator effect by the product removal pump.

Stage II: Drying.--This stage included all equipment associated with the drying operation of the model plant. Items in addition to the dryer itself included the cyclocentric sifter and also the portable transfer pump which was used for drying operations when pumping directly

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<sup>1</sup>French, Sammet, and Bressler, 545.



from a storage vat. The processing operation of this stage included all activities from the point at which condensed product from the evaporator product removal pump was delivered to the dryer high pressure feed pump until the point at which dry powder left the sifter.

Stage III: Bagging.--This stage included all equipment associated with the bagging operation of the model plant. Individual items included the platform scales, bag-closing sewing machine, moisture balance tester, stencil cutting machine, stencil brushes, wooden storage pallets, electric forklift truck and battery charger. The processing operation of this stage included all activities from the point at which dry powder from the sifter was delivered to the bagging spouts until the point at which sealed containers on the loaded pallets were placed into temporary storage in the storage area.

Stage IV: Storage.--The only durable equipment associated with this stage were the wooden pallets and floor space in the storage area occupied by the powder during storage. No specific processing operation was associated with this stage. Sealed powder containers were accumulated until a shipment was made by either truck or railroad transportation.

Stage V: Truck loading.--Durable equipment associated with this stage included wooden pallets, forklift truck, and magnesium loading ramp. The processing operation of this stage included all activities from the point at which the pallets of sealed powder containers were removed from the storage area until the point at which individual bags were positioned in the truck and ready for shipment.

Stage VI: Railroad car loading.--Durable equipment associated with this stage included the wooden pallets, forklift truck, and magnesium loading ramp. The processing operation of this stage included all activities from the point at which the pallets of sealed powder



containers were removed from the storage area until the point at which individual bags were positioned in the railroad car and ready for shipment.

#### Summary of production run phases

The daily activities of a dairy processing plant tend to exhibit certain cyclical characteristics due to the cleanup requirements of dairy equipment. Generally speaking, this cycle commences with the preparation of the processing equipment for the day's production in what might be referred to as a "preparation" period. This preparation period will tend to be of about the same duration from day to day with little or no influence resulting from variations in the length of processing during either preceding or following periods of processing. The cost element requirements for the "preparation" periods will be roughly in proportion to the number of production cycles.

The preparation period is then followed by a period of more or less continuous processing at fixed output rates for various items of equipment. Variations in the quantity of final product are achieved by adjusting the duration of this processing period. Since variations in the cost element requirements are approximately proportionate to the periods of these processing periods they are also then roughly in proportion to variations in the quantity of final product processed.

The processing period is in turn followed by a period in which the processing is discontinued and the equipment is dismantled and cleaned for the next day's production run. This period may be identified simply as a "post-processing" period. Again, this period will tend to be roughly the same duration over very wide ranges of daily production. Only at quite large volumes of daily production will the cleanup periods

begin to show a proportionality to the quantity of production. The cost element requirements for these "post-processing" periods, as for the "pre-processing" periods, will tend to be roughly in proportion to the number of production runs or cycles.

The complete cycle of activity can be referred to as a "production run" and is centered around the single period of more or less continuous processing activity. Most dairy plants use a twenty-four hour cycle. However, there is the possibility of using a cycle longer or shorter than twenty-four hours in order to accomodate a plant's individual activities. A longer cycle would permit proportionately greater processing per cleanup cycle. The ultimate length of a production run would be limited by the cleanup requirements of the equipment involved and would not be the same for all equipment. For this study, the production run of the model plant was assigned a twenty-four hour time restriction.

A calculation of the cost element requirements could proceed for each stage on the basis of the preceding three subdivisions of the production run. The analysis could be made sufficiently precise and the linearity assumptions would be valid. For this study, however, it was decided to break the production run periods down into smaller fragments. Although this election makes for ease of data collection, it will be found to exact its toll during subsequent aggregation procedures.

The "production run decision points" from the previous "definitions" section were used for the definition of the "production run phases." These phases constitute the framework for all data collection and presentation and extensive use of the concept is made in the cost element requirement calculations of Appendix H. The laborious descriptions of the limits for each of the individual phases has been relegated to Appendix C.



### Final product of the model plant

The case study plant produced several different types of dry milk powder for commercial sale. Variations in the final product were effected during the heat treatment of the skim milk prior to evaporation. These various final products were identified by plant personnel to be as follows: cottage cheese grade powder, ice cream grade (medium heat) powder, high heat powder, and baker's special powder.

The case study plant final product was further differentiated by being produced under either grade A sanitary conditions or under standard sanitary requirements, and by either screening the dry powder in order to separate the larger particles for sale as "instant" powder or by bagging and sale of the unscreened powder. Due to the methods used by this study for the measurement of cost element requirements, however, none of the above products involved any measurable variations in cost element requirement. Therefore, for the purpose of the cost calculations in this study, the above products were essentially indistinguishable.

The classification of final products to be used for this study will be based upon variations in the processing technique that involved measurable variations in the cost element requirements. The definition of "final products" that will be presented will not be based upon the previous descriptions and will have no close parallel in common plant phraseology. In fact, the distinction between "final products" to be presented for use in this study will involve factors normally considered to be "indistinguishable" to plant personnel in daily operations.

The milk powder itself will be assumed to be a type acceptable to milk powder purchasers as extra-grade high-heat powder. The general grading requirements set by the American Dry Milk Institute are quoted for general reference.



1. All nonfat dry milk, dry whole milk, and dry buttermilk for human consumption shall conform in all respects to federal and state government regulations in force at the present time or that may subsequently be issued from time to time.
2. The factory and factory equipment used in the manufacture of the above dry milk products shall be maintained in a strictly sanitary condition and shall comply in every respect with the latest Sanitary/Quality Standards Code (Bulletin 915) published by the American Dry Milk Institute, Inc.
3. The dry milk product shall be made from fresh, sweet milk to which no preservative, alkali, neutralizing agent or other chemical has been added and which has been pasteurized in the liquid state either before or during the process of manufacture at a temperature of 145° F. for 30 minutes or its equivalent in bacterial destruction.
4. The dry milk product shall be reasonably uniform in composition. The color shall be white or cream and free from a brown or yellow color typical of overheated product and free from any other unnatural color. It shall be substantially free from brown specks.
5. The flavor and odor of the dry milk product in the dry form or on reliquefaction shall be sweet, clean and free from rancid, tallowy, fishy, cheesy, soapy or other objectionable flavors and odors.
6. The dry milk product shall be packed in substantial containers suitable to protect and preserve the contents without significant impairment of quality with respect to sanitation, contamination and moisture content under various customary conditions of handling, transportation and storage.
7. The presumptive coliform estimate of the dry milk product shall not exceed 90 per gram.
8. The dry milk product shall be free from extraneous matter as described under Sec. 402(a) of the Federal Food, Drug and Cosmetic Act.<sup>1</sup>

Excerpts from United States Standards for Grades of Nonfat Dry Milk covering additional requirements for "extra-grade" dry milk are presented in Appendix K. Also included in that section are the definition of nonfat dry milk, nomenclature of U.S. grades and heat treatment

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<sup>1</sup>Standards for Grades for the Dry Milk Industry Including Methods of Analysis, Bulletin 916 (Chicago: The American Dry Milk Institute, Inc., 1962), p. 5.

classifications, test methods, and other grading and standardization topics.

The type of product differentiation defined for purposes of the present study involved variations in cost element requirements discernible to the measurements used in the study. These variations can be grouped into three general classifications as follows:

1. Variations in the types of weekly production periods, i.e., five-day production weeks versus six-day weeks (as defined in Appendix G),
2. Variations in the types of powder containers used in the bagging stage, i.e., fifty-pound unprinted (plain) paper bags with a plastic inner liner, versus either hundred-pound plain paper bags with a liner, or hundred-pound paper bags with a liner and made to government specifications, and
3. Variations in the type of transportation for which loading of powder containers must be provided, i.e., truck transportation versus railroad car transportation.

Each of the above classifications of variations that have been defined for the model plant will be considered in greater detail in the remainder of this section.

#### Variation in type of processing week

The definitions for the five-day and six-day weeks that will be used are an attempt to incorporate into the processing costs of the model plant some of the processing time that was observed to be lost during processing in the drying stage. A description of the analysis for this "downtime" can be found in Appendix G. Production of an otherwise similar type of milk powder during these two types of processing week definitions



will result in different cost element requirements. The two definitions will therefore be considered to indicate two different "final products" for the purposes of this study.

#### Variation in type of container

Packaging in any of three different types of containers was considered: fifty-pound plain bags, hundred-pound plain bags, and hundred-pound bags for government grade powder. These three types of containers were each priced differently and therefore were considered to specify a different type of final product.

In addition to variations in the prices of the containers, there were also some alterations in processing techniques involved when bagging in the fifty-pound bags as opposed to the hundred-pound bags. The smaller bags required handling twice as many individual bags. This required the addition of another man in the bagging room and this resulted in an additional labor charge during "fifty-pound bag" operations.

#### Variation in type of transportation

This study did not take into consideration transportation costs as such but instead used an FOB plant specification. There were, however, considerable differences in the loading requirements for different types of transportation. This study considered two different final products to be identified by the variations in "loading" cost element requirements for two types of transportation.

Semi-trailer trucks could be loaded at the dock in the plant. The interiors of the trucks were generally in good condition and required very little work in preparation for loading. The loading dock was convenient to the storage area and little time was lost in shuttling



the forklift and pallets from the storage area to the truck and back.

Cost element requirements were higher, in comparison, when shipment was made by railroad car. Railroad cars required considerable preparation before powder could be loaded. The distance between the plant and railroad loading dock was another factor contributing to greater cost requirements. Pallets were loaded first into a semi-trailer truck for transfer to the railroad loading dock and then the individual bags were loaded into the railroad car.

#### Summary of final product specifications

The aggregation procedure and specification of an average cost for a particular volume of powder in Part V will require selection of one of the alternatives in each of the above sets. There is a total of twelve different possible combinations of the processing alternatives. It may be noted at this point, however, that the case study plant utilized only six of this possible twelve combinations. All of these alternatives are summarized in Table 8 and the six types used by the plant studied are indicated.

TABLE 8.--Summary of model plant processing combinations associated with distinct final products

Type of transportation	Type of processing week	
	5-day weeks	6-day weeks
Truck . . . . .	50-lb. plain bags <sup>a</sup>	50-lb. plain bags <sup>a</sup>
Truck . . . . .	100-lb. plain bags <sup>a</sup>	100-lb. plain bags <sup>a</sup>
Truck . . . . .	100-lb. gov't bags	100-lb. gov't bags
RR car . . . . .	50-lb. plain bags	50-lb. plain bags
RR car . . . . .	100-lb. plain bags	100-lb. plain bags
RR car . . . . .	100-lb. gov't bags <sup>a</sup>	100-lb. gov't bags <sup>a</sup>

<sup>a</sup>These six processing combinations were used by the case study plant.

### Simplifying technological assumptions

The purpose of this section will be to provide a summary of some of the more important technological assumptions that were made in the course of this study. These assumptions are, for the most part, expositional and could be removed with substitution of the additional energy which would then be required to handle the data. Where the assumptions may not reasonably represent actual circumstances, such a reservation will be noted.

General setting of the milk drying process.---For the purposes of this analysis it will be assumed that the milk drying process is embedded in the general setting of a multi-product dairy manufacturing plant. The milk procurement, fluid receiving, and cream separating functions are considered to be performed by the associated multi-product plant in connection with processing of its grade A products. No costs will be allocated to the dry milk powder for those functions. This assumption will also be the basis for an assumption as to the availability of labor in the model plant, allocations of various annual fixed costs in Part IV, and assignment of individual cost element unit prices in Appendix J.

Availability of labor.---Labor will be assumed to be freely available in unlimited quantities. This implies that there are no considerations given to the minimum periods for which a key man can be hired without risk of losing the man, or of overtime pay for production levels requiring a work day in excess of the standard eight-hour day or forty-hour week.

This is not an unrealistic assumption for a milk drying process incorporated into a multi-product dairy plant, however. There are many other processes being conducted which will have varying levels of labor requirements during any given day. In practice the plant foreman can



juggle his various production activities sufficiently to absorb transient oversupplies or shortages of labor in the various processes by combination with other processes.

Final products.--All final products defined for this study are assumed to have the same cost element requirements in the evaporating stage. Since many of the products actually produced by the plant studied involved variations in temperatures of the fluid milk leaving the live steam heater it is likely that there could be some variation in the steam requirement. Operating conditions for the evaporator are the same for all the products, however, and it is probable that the net difference is not large.

Processing rate.--Equipment used in the various stages was capable of varying processing rates. The maximum rate was not identical for all units. The equipment was assumed to be completely interconnected during the processing phase of the production run. As a result it was necessary for all equipment to operate at the processing rate compatible with the slowest unit of equipment. For the plant studied the evaporator was the limiting unit.

Evaporator-dryer interconnection.--The dryer is assumed to receive all of the condensed product from the evaporator. The consequence of this interdependence can be handled in either of two ways when there is an interruption due to a stoppage of the dryer operation. Either method will be consistent with the analysis of this study but will yield slightly different results.

A first method would be to assume that the evaporator output will be run to the storage vat during periods of dryer stoppages. Direct flow to the dryer would be restored when the dryer resumed operation. When the evaporator terminated processing for the production run, the dryer



could be switched to pump from the storage vat and then process that condensed milk that had been diverted during the stoppage.

The longer cleanup period for the evaporating stage made it the limiting consideration for the maximum processing period possible in a production run. The above assumption would permit the dryer to continue after evaporator processing had been terminated. This would retain maximum production period capabilities within the twenty-four hour time restriction. This is the assumption used in this study.

Another possible approach would have been to assume the same diversion of condensed milk to the storage vat during stoppages. It could then be assumed that this condensed product was sold or used for purposes other than milk powder. In order to be consistent with the analysis of this study, this quantity of condensed milk would have to bear the variable cost element expenses from the evaporating stage. It would not, however, have any of the fixed cost element expenses allocated to it. This technique would more closely resemble the empirical practices of the plant studied than would the technique presented first. However, since it would result in a further reduction in the quantity of powder that could be produced during a production run, it was not used.

Clean-up phases.--The clean-up phase is assumed to be of a single, constant duration for each stage. This implies that the cleaning requirements are not affected in any way by the length of processing during the operating phase. This is undoubtedly not applicable for an unlimited period of processing. It is probable, however, that it is not an unreasonable assumption for the range of processing periods considered in this study. It is progressively more subject to challenge, however, at the longest periods. In addition, it is likely that the evaporator would begin to show a positive relationship between cleaning requirements

and processing time sooner than the dryer. It is quite likely that both stages would require changes in this assumption if the production run period were lengthened to thirty-six hours.

Variable phases.--The length of each of the variable phases is assumed to be directly proportional to the quantity of product processed. This implies that the processing phase has been defined in such a manner that production commences simultaneously with the start of the phase and reaches its full processing rate instantaneously. Similarly, production must continue at full volume until the end of the phase and then be terminated instantaneously.

Actual processing does not fit well into this abstraction. In fact, the processing rate tends to accelerate from zero to normal flow over a measurable length of time at the start of the period. Subsequently, it falls off to zero over a measurable period after the cessation of processing.

By expressing total production in relation to total processing time for a period of several months, however, an average rate can be obtained that will be consistent with the proportionality assumption. The average rate will be considerably greater than actual processing at the very first of the processing period. It will probably be somewhat smaller than the actual rate during the bulk of the period and it will disregard that portion of the product which is extracted from the stage after termination of inputs of raw product. The discrepancy is not likely to be unacceptable for the equipment analyzed in this study, however.

The same proportionality assumption was used for the maintenance phases of the drying and bagging stages. Appendix G presents the analysis of the down-time appearing in the plant records and the reasoning

leading to the proportionality assumption. It is possible that the duration of the maintenance phases were affected by factors other than the duration of the processing period. The proportionality assumption in this case could possibly be replaced by an analysis involving additional variables or non-linear relationships or both.

Total production.--The processing rate for the model plant has been considered to be controlled by the output of the evaporator. Since the processing rate of the evaporator is fixed by engineering considerations variations in total output are achieved by varying the length of the processing periods.

Maximum possible production for the model plant is therefore governed by the maximum possible period of processing. For any given processing day the limiting factor for the length of the processing period will be the length of the cleanup period required. Reference to either Figure 1 of Part III or to Table 40 of Appendix C indicates that the cleanup period for the evaporating stage will be the limiting factor in determining the maximum production capacity for the model plant.



#### IV. DATA COLLECTION

A description of the manner in which the various cost element quantities were determined will be presented in this part. The funds available to this study were limited and therefore many of the measurements were obtained by repeated interviews with the plant personnel rather than by direct observation. The procedures followed will be presented for both direct cost elements and annual fixed cost elements.

##### Direct Cost Elements

Cost elements presented in this section are those associated with the actual processing period or "production run" as defined in Part III. These cost elements are responsible for the additional costs that are incurred during processing and are therefore referred to as "direct" cost elements. They are the basis for the variable costs incurred by the plant during the year and do not include the annual fixed cost elements.

Following will be a description of the procedures used in calculating requirements for labor, electricity, natural gas, steam, water, cleaners, containers, and supplies. The individual cost element calculations are presented in Appendix H and a summary of these calculations is made at the end of this section.

##### Labor requirements

The labor cost element for this study was defined to be services of operators and helpers employed directly in preparation, operation or

cleanup of each of the stages. This labor cost element did not include a charge for the foreman or plant manager.

These personnel were paid by the hour and were used in other areas of the plant when the stage to which they were principally assigned was not in operation. For this reason, it was considered reasonable to treat all labor as freely available for each level of production.<sup>1</sup> No allowances were incorporated for the under-utilization of labor at low levels of production, or for the necessity of overtime at very high levels of production.

Most of the work stations applicable to this study were manned at all times during the operating phase of the production run. A straight hourly charge was applied to these work stations to produce a straight hourly charge for the stage.

For the load-out stage, and for those phases preceding and following the operating phase of the other stages, a combination of observation supplemented by interviews was used to establish a reasonable value. Actual operations were observed, noting carefully any unusual conditions which could cause the operation to differ from normal. With these observations as a guide, the operators and plant supervisory personnel were interviewed. Initial observations were adjusted to provide a reasonable value, in the judgment of the plant personnel, for normal operations.

No statistical labor studies were attempted and the above observations were open to errors of subjective judgment.

#### Electrical requirements

The feasibility of electrical requirement determination by

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<sup>1</sup>By "freely available" it is meant that although a charge was made for this labor, its supply was not restricted at the specified price per hour.



empirical measurement was explored for possible use in this study. The electrical meters installed at the case study plant were inappropriate for such a study, however, and installation of equipment adequate for the necessary accuracy proved beyond the resources of the study.

The method of determining electrical requirements which was used in place of actual measurements made use of the relationship between the rated horsepower of an electrical motor, as stated on the manufacturer's name plate, and the power consumption of the motor under full load.<sup>1</sup> The various electrical motors were observed during processing operations in the plant and the periods of operation during each of the production run phases was noted. The energy requirement for each motor was then calculated by reference to the rated horsepower. This method of estimation implied several assumptions, and the result of the calculations was subject to error to the degree that the assumptions did not adequately represent conditions being estimated.

For the individual energy requirement calculations it was assumed that all motors were operating under full load during all periods of operation. It is probable that some motors were not operating under full load conditions but it was not possible to determine the actual individual loading conditions. This assumption of full loading is synonymous with assuming that each motor is delivering power equal to the rated horsepower stated on the name plate. No adjustment was attempted for loading surges as experienced by the two evaporator CIP motors during the cleanup phase of the production run.

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<sup>1</sup>An estimating function for this relationship was supplied by the Electrical Engineering Department of Kansas State University. This estimating function was not proven by subsequent measurement data.



The following electrical efficiencies were assumed for each electrical motor under full-load conditions ( $\eta_{FL}$ ):<sup>1</sup>

<u>Rated horsepower</u>	<u>Efficiency (<math>\eta_{FL}</math>)</u>
$0 < HP < 1$	0.65
$1 \leq HP < 2$	0.70
$2 \leq HP < 5$	0.80
$5 \leq HP$	0.85

The estimating formula supplied by electrical engineers for electrical requirement calculation under the assumed full-load condition was as follows:

$$KWH_{in_{FL}} = \left[ \frac{(HP_{out}) (0.746)}{\eta_{FL}} \right] (\text{Hours}) \quad (1)$$

where:

$KWH_{in_{FL}}$  = electrical requirement under full load (kilowatt-hours),

$HP_{out}$  = manufacturer's rated full-load output for the motor (horsepower),

$\eta_{FL}$  = full-load electrical efficiency of the motor,

0.746 = a constant relating power in terms of horsepower to power in terms of kilowatts, and

Hours = hours of operation for the motor under full load.

The rated horsepower of an electric motor can also be used to develop reasonable power requirements under conditions of no-load. The full load electrical efficiencies  $\left( \eta_{FL} \right)$  for the motors reflected

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<sup>1</sup>Paul L. Kelley et al., A Linear Programming Model of a Surplus Milk Plant, Technical Bulletin 123, (Manhattan: Kansas State University, April, 1962), p. 53.

allowance for two types of power losses at full load  $(P_{\text{loss}_{\text{FL}}})$ . The first type of power loss was a fixed loss  $(P_{\text{loss}_{\text{FL}}}^{\text{FP}})$  including losses due to friction and windage within the motor and was independent of load. The second type of power loss was a variable loss  $(P_{\text{loss}_{\text{FL}}}^{\text{VP}})$  including losses electrical in nature and was dependent upon load. The ratio of the total power loss at full load to the total power input at full load  $(P_{\text{in}_{\text{FL}}})$  is:

$$K_{\text{FL}} = \frac{(P_{\text{loss}_{\text{FL}}}^{\text{FP}}) + (P_{\text{loss}_{\text{FL}}}^{\text{VP}})}{P_{\text{in}_{\text{FL}}}} \quad (2)$$

Similarly, the ratio of the total power loss at no load to the total power input at no load may be defined as:

$$K_{\text{NL}} = \frac{(P_{\text{loss}_{\text{NL}}}^{\text{FP}}) + (P_{\text{loss}_{\text{NL}}}^{\text{VP}})}{P_{\text{in}_{\text{NL}}}} \quad (3)$$

Total power loss at full load can be assumed to be divided approximately equally between the fixed and variable losses defined above. Since variable power losses approach zero under no-load conditions, total power requirement for a motor under no-load conditions is approximately proportional to its fixed power losses.

The above assumptions and relationships can be summarized in terms of the following notations:

$$(1) \quad \eta_{\text{FL}} = \frac{P_{\text{out}_{\text{FL}}}}{P_{\text{in}_{\text{FL}}}} \quad .$$

$$(2) \quad K_{\text{FL}} = 1 - \eta_{\text{FL}} = 1 - \left( \frac{P_{\text{out}_{\text{FL}}}}{P_{\text{in}_{\text{FL}}}} \right) = \frac{(P_{\text{in}_{\text{FL}}}) - (P_{\text{out}_{\text{FL}}})}{P_{\text{in}_{\text{FL}}}} \\ = \frac{P_{\text{loss}_{\text{FL}}}}{P_{\text{in}_{\text{FL}}}} \quad ,$$

$$(3) P_{\text{loss}_{\text{FL}}} = (P_{\text{loss}_{\text{FL}}}^{\text{FP}}) + (P_{\text{loss}_{\text{FL}}}^{\text{VP}})$$

where it is assumed that:

$$P_{\text{loss}_{\text{FL}}}^{\text{FP}} \approx \frac{P_{\text{loss}_{\text{FL}}}}{2} , \text{ and}$$

$$P_{\text{loss}_{\text{FL}}}^{\text{VP}} \approx \frac{P_{\text{loss}_{\text{FL}}}}{2} .$$

Also:

$$P_{\text{loss}_{\text{NL}}} = (P_{\text{loss}_{\text{NL}}}^{\text{FP}}) + (P_{\text{loss}_{\text{NL}}}^{\text{VP}})$$

where:

$$P_{\text{loss}_{\text{NL}}}^{\text{FP}} \approx \frac{P_{\text{loss}_{\text{FL}}}}{2} , \text{ and}$$

$$P_{\text{loss}_{\text{NL}}}^{\text{VP}} \approx 0 ,$$

then:

$$P_{\text{loss}_{\text{NL}}} \approx P_{\text{loss}_{\text{NL}}}^{\text{FP}} .$$

$$(4) P_{\text{loss}_{\text{FL}}} = (P_{\text{in}_{\text{FL}}}) (K_{\text{FL}}) = \left( \frac{P_{\text{out}_{\text{FL}}}}{\text{FL}} \right) (K_{\text{FL}}) .$$

$$(5) P_{\text{loss}_{\text{NL}}} = (P_{\text{in}_{\text{NL}}}) (K_{\text{NL}}) = \left( \frac{P_{\text{out}_{\text{FL}}}}{\text{FL}} \right) (K_{\text{FL}}) (0.5) ,$$

$$P_{\text{in}_{\text{NL}}} = P_{\text{loss}_{\text{NL}}} = \left[ \frac{(P_{\text{out}_{\text{FL}}}) (0.746)}{\text{FL}} \right] (K_{\text{FL}}) (0.5) .$$



$$(6) \text{ KWH}_{\text{in}_{\text{NL}}} = \left( P_{\text{in}_{\text{NL}}} \right) \left( \text{Hours} \right)$$

where:

$\eta_{\text{FL}}$  = efficiency of the motor under full load (per unit),

$\text{FP}_{\text{loss}_{\text{FL}}}$  = fixed power loss of the motor under full load (KW),

$\text{FP}_{\text{loss}_{\text{NL}}}$  = fixed power loss of the motor under no load (KW),

$\text{HP}_{\text{out}_{\text{FL}}}$  = rated horsepower of the motor as stated on the name plate,

$K_{\text{FL}}$  = ratio of total power loss at full load to the total power input at full load,

$K_{\text{NL}}$  = ratio of total power loss at no load to total power input at no load,

$\text{KWH}_{\text{in}_{\text{NL}}}$  = electrical requirement under no load (KWH),

$P_{\text{in}_{\text{FL}}}$  = power into the motor under full load (KW),

$P_{\text{in}_{\text{NL}}}$  = power into the motor under no load (KW),

$P_{\text{loss}_{\text{FL}}}$  = power loss of the motor under full load (KW),

$P_{\text{loss}_{\text{NL}}}$  = power loss of the motor under no load (KW),

$P_{\text{out}_{\text{FL}}}$  = power out of the motor under full load (KW),

$\text{VP}_{\text{loss}_{\text{FL}}}$  = variable power loss of the motor under full load (KW), and

$\text{VP}_{\text{loss}_{\text{NL}}}$  = variable power loss of the motor under no load (KW).

### Natural gas requirements

There were no adequate plant records of gas consumption by the dryer available for use in this study. The monthly gas consumption records that had been kept for a plant-owned gas meter installed just prior to the dryer burners gave no break-down of consumption into warm-up and operating requirements. Natural gas requirements for the model plant were therefore calculated by utilizing timed gas usage measurements obtained from the previously mentioned plant-owned gas meter. Periods of operation which were reasonably representative of normal dryer operations were selected for the measurements which were taken in the following manner.

Both the plant-owned gas meter and another gas meter owned by the gas company were located in the gas line ahead of a pressure reducer. These meters recorded volumes of gas under the higher pressure conditions of the main gas distribution pipe line. The plant was billed for its gas usage on the basis of gas volume at atmospheric pressure, however, and it was therefore necessary to adjust the meter readings obtained from the plant-owned gas meter during this study for the difference in the measured gas volumes which would result from the two pressure conditions. The adjustment was accomplished by reference to the following relationship:

$$P_1 V_1 = P_2 V_2 \quad (1)$$

where  $P_1$  and  $V_1$  can be taken as the pressure and volume respectively under the first set of conditions (gas company line pressure), and where  $P_2 V_2$  can be taken as the pressure and volume respectively under the second set of conditions (atmospheric pressure).

Relationship (1) can be restated for use in calculation of the gas usage volumes at atmospheric pressure ( $V_2$ ) as follows:

$$V_2 = \frac{P_1 V_1}{P_2} = \frac{P_1}{P_2} (V_1) \quad (2)$$

where:

$V_2$  = equivalent volume of gas at atmospheric pressure  
(cubic feet of gas),

$V_1$  = metered volume of gas at the distribution pipe line  
pressure (cubic feet of gas),

$P_2$  = atmospheric pressure (pounds absolute), and

$P_1$  = distribution pipe line pressure (pounds absolute).

Relationship (2) calls for pressures in "absolute" values therefore requiring an additional relationship for restating observed pressure readings that were in terms of "pounds gauge." This calculation can be performed as follows:

$$P_{sia.} = P_{sig.} + P_{sib.} \quad (3)$$

where:

$P_{sia.}$  = absolute pressure (pounds per square inch),

$P_{sig.}$  = gauge pressure (pounds per square inch), and

$P_{sib.}$  = barometric pressure (pounds per square inch).

Distribution pipe line pressure was observed from a circular recording chart used by the gas company for billing purposes. An average value of 32.5 psig. was observed on this chart for the period of meter measurements. Barometric pressure is generally accepted to be approximately equal to 14.7 psib. for calculation purposes. The distribution pipe line pressure can be obtained in absolute terms from relationship (3) as follows:

$$\begin{aligned} P_{sia.} &= P_{sig.} + P_{sib.} \\ &= 32.5 \text{ psig.} + 14.7 \text{ psib.} \end{aligned} \quad (3)$$



$$= 47.2 \text{ psia.}$$

Similarly, atmospheric pressure can be obtained in absolute terms where observed gauge pressure is equal to zero:

$$\begin{aligned} \text{Psia.} &= \text{Psig.} + \text{Psib.} & (3) \\ &= 0.0 \text{ psig.} + 14.7 \text{ psib.} \\ &= 14.7 \text{ psia.} \end{aligned}$$

Specification of these values permit restatement of relationship (2) in the form that will be used for calculations:

$$V_2 = \frac{P_1}{P_2} (V_1) \quad (2)$$

$$= K (V_1) \quad (4)$$

$$= \frac{47.2 \text{ psia.}}{14.7 \text{ psia.}} (V_1)$$

$$= 3.211 (V_1) .$$

Gas meter readings ( $V_1$ ) taken from the plant-owned meter at the higher distribution pipe line pressure ( $P_1$ ) were corrected for restatement at atmospheric pressure ( $P_2$ ) by application of a constant conversion factor ( $K = 3.211$ ). The result ( $V_2$ ), stated in terms of cubic feet of gas at atmospheric pressure, is essentially the same quantity of gas for which the plant would be billed by a gas company.

Average hourly requirements for a representative two-hour period are presented in Table 9 for illustration.<sup>1</sup> The actual consumption figure used for calculations in this study was 9,600 cubic feet per hour. This requirement agreed very well with the 10,000 cubic feet per hour average value estimated by plant personnel from monthly observations of

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<sup>1</sup>"Representative" was a judgement definition.

the plant-owned gas meter. The slightly higher requirement figure calculated by the plant can be justified by noting that a reading obtained monthly would average all gas usage by the dryer for the monthly period. The quantities of gas required during warm-up and shutting-down phases would therefore be in addition to the actual requirement during drying.

TABLE 9.--Dryer gas requirements for the case study plant during a representative two-hour period

Time	Elapsed time (minutes)	Meter reading	Usage	$V_1$ /hr.	$V_2$ /hr.
9:15	--	76703	---	-----	-----
9:30	15	77470	767	3,068	9,851
9:45	15	78225	755	3,020	9,697
10:00	15	78971	746	2,984	9,582
10:20	20	79969	998	2,994	9,614
10:30	10	80469	500	3,000	9,633
11:00	30	81953	1,484	2,968	9,530
11:18	18	82847	894	2,980	9,569
Total $V_2$					67,476
Average $V_2$					9,639

### Steam requirements

The evaporating stage equipment was the only equipment assigned a steam requirement. There were no records for the quantity of steam used by the evaporator. The possibility of installing a steam meter was explored but abandoned as impractical for the resources of this study.

The engineering specifications established by the manufacturer were taken as the alternative basis for the steam requirement calculations. It was assumed that these specifications could be accepted as closely approximating the true requirements.

The four points of the stage at which steam was required were the hogging jets (41), the intermediate jets (39), the live steam heater (14) and the thermo-compressor (21). The manufacturer supplied data for the last three as follows:

Intermediate jets	367 lbs. per hour,
Preheater	920 lbs. per hour, and
Thermo-compressor	7,525 lbs. per hour. <sup>1</sup>

These are the three main components requiring steam and the only ones which are in operation during the operating phase.

The remaining hogging jets are used only during the initial vacuum buildup at the start of the production run. Although no specifications by the manufacturer were given, an approximation of their usage was made based upon the following reasoning. The diameter of the intermediate jet was known from engineering specifications to be equal to one inch. From recollections of observations made by the plant engineer during past maintenance, an estimate was made of the hogging jet diameter as at least three-quarters of an inch.

If the steam capacity of the two steam jets can be assumed to vary in proportion to the area of the steam opening in the jets, and if the steam pressure can be assumed to be equal for both jets, then the capacity of the two steam jets can be assumed to be proportional to the squares of the two radii. This relationship can be illustrated in notational form as follows:

$$\frac{C_b}{C_a} \approx \frac{(R_b)^2}{(R_a)^2}$$

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<sup>1</sup>See Table 6 in Part III.



where:

$R_a$  = radius of the intermediate jet (one-half inch),

$R_b$  = radius of the hogging jet (three-eighths inch),

$C_a$  = capacity of the intermediate jet (367 lbs./hr.), and

$C_b$  = capacity of the hogging jet,

then:

$$\frac{C_b}{367 \text{ lbs./hr.}} \approx \frac{(0.375 \text{ in.})^2}{(0.500 \text{ in.})^2}$$

$$C_b \approx (367 \text{ lbs./hr.}) \left( \frac{0.1406 \text{ sq. in.}}{0.2500 \text{ sq. in.}} \right)$$

$$(367 \text{ lbs./hr.}) (0.5624) = 206.4008 \text{ lbs. per hr.}$$

$$C_b \approx 206 \text{ pounds steam per hour.}$$

With the hourly steam requirements specified for each steam-using item of equipment, an additional allowance was made for the efficiency of the steam distribution system. A distribution system efficiency of ninety percent was assumed and each individual steam requirement was adjusted as follows:

Hogging jet:

$$\frac{206 \text{ lbs./hr.}}{0.90} = 228.8 \text{ lbs./hr.} \approx 229 \text{ lbs. per hour.}$$

Intermediate jet:

$$\frac{397 \text{ lbs./hr.}}{0.90} = 441.1 \text{ lbs/hr.} \approx 441 \text{ lbs. per hour.}$$

Preheater:

$$\frac{920 \text{ lbs./hr.}}{0.90} = 1,022.2 \text{ lbs./hr.} \approx 1,022 \text{ lbs. per hour.}$$

Thermo-compressor:

$$\frac{7,525 \text{ lbs./hr.}}{0.90} = 8,361.1 \text{ lbs./hr.} \approx 8,361 \text{ lbs. per hour.}$$

These final figures express the individual steam requirements for delivery of steam at the boiler. The steam cost figure from Appendix J which will be applied will also be in terms of steam generated and available at the boiler.

#### Water requirements

No actual measurement was attempted for the water requirements of any of the stages. The following techniques were used to estimate different requirements.

Vats, which water was pumped to or from during cleanup of the evaporating stage, were checked to get an approximation of the quantity used at that point. Minor uses were lumped together and estimated in round figures.

An indication of the volume of liquid that could be pumped by the dryer high-pressure feed pump can be obtained by figuring the liquid equivalent processing rate. An hourly rate of 3,500 pounds of powder would be equivalent to an hourly rate of 8,140 pounds of condensed product at 43 percent solids. For condensed product weighing 9.24 pounds per gallon,<sup>1</sup> this would be equal to 880.95 gallons pumped per hour at a pressure of approximately 3,500 pounds per square inch. It was reasonable to allow a rate of five hundred gallons of water an hour when pumping at the lower pressure of 1,500 pounds per square inch during the short periods of warm-up and shutting-down.

Water required for cleanup of the bagging stage was figured from the flow rate of the hose used which is approximately ten gallons per minute at full pressure. If the hose was used for the twenty minutes at

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<sup>1</sup>Arthur W. Farrall, Engineering for Dairy and Food Products (New York: John Wiley and Sons, Inc., 1963), p. 6.

half pressure and if it then had a rate of flow of five gallons per minute a quantity of one hundred gallons would be a reasonable value for the cleanup phase of the bagging stage.

#### Cleaner requirements

There were four different cleaners used which were alkali cleaner, acid cleaner, Shur-spray and chlorine. All except the chlorine were added in the same measured quantities during each cleanup period. The chlorine was mixed with water when used for spraying the inside of the evaporator chests and separators during hookup. It was necessary to estimate this quantity.

#### Container requirements

Container requirements were stated on the basis of an exact fifty-pound or hundred-pound fill of each container. There was, in fact, a very slight overfill of each container in order to insure that the net weight of the bag would be adequate. Over a short period of observation this overfill appeared to average approximately 0.10 pound to 0.15 pound per bag after allowing for the weight of the bag. It was therefore decided to assume even powder weights for all filled bags and to disregard the overfill.

#### Supply requirements

The supplies for which this study attempted measurement were felt roofing paper, malathion insecticide, and lumber. Each of these supplies were used during the preparation of the railroad car for shipment of powder.

The roofing paper and insecticide requirements were easy to estimate since a specific amount was purchased for each shipment and each item



TABLE 10.---Fixed direct cost element requirements per production run by stages summarized from section I of Appendix H

Cost elements	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Class "A" labor (hrs.) . . .	12.34	3.92	0.43	--	--	--
Class "B" labor (hrs.) . . .	--	--	0.41	--	--	--
Class "C" labor (hrs.): <sup>a</sup>						
50-lb. bag oper'ns . . .	--	--	0.41	--	--	--
100-lb. bag oper'ns . . .	--	--	--	--	--	--
Electricity (KWH). . . . .	189.1295	140.4974	0.0230	--	--	--
Natural gas (cu. ft.) . . .	--	3168.0000	--	--	--	--
Steam (lbs.) . . . . .	10014.8610	--	--	--	--	--
Water (gals.) . . . . .	540.0000	735.0000	100.0000	--	--	--
Chlorine (pints) . . . . .	1.0000	--	--	--	--	--
LC-10 acid (gals.) . . . . .	1.5000	--	--	--	--	--
Shur-spray acid (lbs.) . . .	--	10.0000	--	--	--	--
Alkali cleaner (lbs.) . . .	80.0000	10.0000	--	--	--	--
Containers: <sup>a</sup>						
50-lb. plain bags . . . .	--	--	--	--	--	--
100-lb. plain bags . . . .	--	--	--	--	--	--
100-lb. gov't bags . . . .	--	--	--	--	--	--
Felt roofing paper (roll) .	--	--	--	--	--	--
Insecticide (pint). . . . .	--	--	--	--	--	--
Lumber (bd. ft.) . . . . .	--	--	--	--	--	--

<sup>a</sup>Only one cost element requirement in this category is applicable for each product.

TABLE 11.--Variable direct cost element requirements per hundredweight of powder by stages for five-day weeks summarized from section II of Appendix H

Cost elements	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Class "A" labor (hrs.) .	0.0287202536	0.0033487815	0.0264226333	--	0.0029677419	0.0062500000
Class "B" labor (hrs.) .	--	0.0006663099	0.0291051050	--	0.0029677419	0.0062500000
Class "C" labor (hrs.): <sup>a</sup>						
50-lb. bag oper'ns . .	--	0.0006663099	0.0291051050	--	0.0029677419	0.0250000000
100-lb. bag oper'ns .	--	--	--	--	0.0029677419	0.0250000000
Electricity (KWH) . . .	2.4025640946	7.0787043337	0.0143355940	--	--	--
Natural gas (cu. ft.) .	--	277.8326109840	--	--	--	--
Steam (lbs.) . . . . .	253.9444823312	--	--	--	--	--
Water (gals.) . . . . .	--	0.1025313100	--	--	--	--
Chlorine (pints) . . . .	--	--	--	--	--	--
LC-10 acid (gals.) . . .	--	--	--	--	--	--
Shur-spray acid (lbs.) .	--	--	--	--	--	--
Alkali cleaner (lbs.) .	--	--	--	--	--	--
Containers: <sup>a</sup>						
50-lb. plain bags . .	--	--	2.0000000000	--	--	--
100-lb. plain bags . .	--	--	1.0000000000	--	--	--
100-lb. gov't bags . .	--	--	1.0000000000	--	--	--
Felt roofing paper (roll)	--	--	--	--	--	0.0012500000
Insecticide (pint) . . .	--	--	--	--	--	0.0003125000
Lumber (bd. ft.) . . . .	--	--	--	--	--	0.0583333333

<sup>a</sup>Only one cost element requirement in this category is applicable for each product.

TABLE 12.---Variable direct cost element requirements per hundredweight of powder by stages for six-day weeks summarized from section II of Appendix H

Cost elements	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Class "A" labor (hrs.) .	0.0287202536	0.0046584250	0.0264226333	--	0.0029677419	0.0062500000
Class "B" labor (hrs.) .	--	0.0015394056	0.0295416528	--	0.0029677419	0.0062500000
Class "C" labor (hrs.): <sup>a</sup>						
50-lb. bag oper'ns .	--	0.0015394056	0.0295416528	--	0.0029677419	0.0250000000
100-lb. bag oper'ns .	--	--	--	--	0.0029677419	0.0250000000
Electricity (KWH). . . .	2.4025640946	7.1719983606	0.0144608832	--	--	--
Natural gas (cu. ft.). .	--	280.2547616640	--	--	--	--
Steam (lbs.) . . . . .	253.9444823312	--	--	--	--	--
Water (gals.) . . . . .	--	0.2191355200	--	--	--	--
Chlorine (pints) . . . .	--	--	--	--	--	--
LC-10 acid (gals.) . . .	--	--	--	--	--	--
Shur-spray acid (lbs.) .	--	--	--	--	--	--
Alkali cleaner (lbs.) .	--	--	--	--	--	--
Containers: <sup>a</sup>						
50-lb. plain bags . .	--	--	2.0000000000	--	--	--
100-lb. plain bags . .	--	--	1.0000000000	--	--	--
100-lb. gov't bags . .	--	--	1.0000000000	--	--	--
Felt roofing paper (roll)	--	--	--	--	--	0.0012500000
Insecticide (pint) . . .	--	--	--	--	--	0.0003125000
Lumber (bd. ft.) . . . .	--	--	--	--	--	0.0583333333

<sup>a</sup>Only one cost element requirement in this category is applicable for each product.



was used until the quantity on hand was exhausted. Lumber was used in boarding up the car doors whenever it was not possible to use door panels from grain cars. For this study it was assumed that the grain doors were not available and that the doors must be boarded up with one-by-four pine lumber for each shipment.

Other supplies were used for which no measurement was attempted and included stencil ink, stencil cardboard, string for tying and sewing the tops of the powder bags, nails for attaching the felt roofing paper in the railroad cars, nails for boarding up the railroad car doors, and cardboard used in covering rough spots in the railroad car. Each of these elements were used in quantities so small that the requirements on a hundredweight basis would be insignificant. Cardboard used was obtained from discarded shipping containers and had no further monetary value.

#### Annual Fixed Cost Elements

A description of the techniques used in establishing the annual fixed cost element requirements for the model plant will be presented in this section. For the purposes of this study each of these annual fixed cost element requirements was considered to be fixed for an annual period and to be unaffected by variations in the quantity of product processed during that annual period.

The six annual fixed cost elements that will be presented in this section include administrative expenses, fixed labor, repairs and maintenance, depreciation, interest, and property taxes.<sup>1</sup> The annual costs assigned to each of the items are summarized at the end of this section.

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<sup>1</sup>Sewage disposal expenses are often an item of considerable annual expense in many areas. It is, however, an expense that varies considerably from area to area and frequently subject to lobbying considerations in local governments. This study will not include a cost for sewage service.

Administrative expense

The basis for figures presented in this section was a summary of case study plant administrative expenses for 1964. Not all of the plant's expenses were considered relevant to this study, however.

It was necessary to adjust total annual expense of the plant for the difference in size between the milk drying process and the plant as a whole. It was apparent that practically any criteria that could be used would be arbitrary and might create misallocation on some items. It was decided, therefore, to use the relationship between the annual powder sales and the total sales for the case study plant as an approximation for this allocation. This basis represents an assumption as to the relative importance that the milk drying process might have in the total operations of a plant in which it might be located. An indication of the volume of production for the case study plant drying process can be obtained from the average annual powder production. For the two-year period covered in Table 43, of Appendix E, annual production for the case study plant was 6,992,017 pounds of powder.

The following items are included in the annual administrative expense cost:

- Executive and office salaries,
- Office supplies and expenses,
- Telephone and telegraph,
- Advertising,
- Travel expenses,
- Life insurance:
  - General;
  - Group;
  - Life,
- Subscriptions,
- Legal fees,
- Employer gifts and parties, and
- Depreciation on office equipment.

Total annual administrative expense allocated to the milk drying process in the above manner was \$15,328.



### Fixed labor

Two types of fixed labor were considered. A plant foreman is customary in any plant and represents a cost element of broad application. This cost element was allocated in this study on the basis of the relationship that average annual powder sales bore to average total sales minus average butter department sales. This particular form of correction reflects the fact that the foreman in charge of the drying process was not in charge of the butter department. The fixed labor allocated to the working foreman by this study was \$1,440.

The second type of fixed labor arises from the method used by this study to handle the dryer preventive maintenance. Appendix G defines a "five-day" processing week to occur when a period of preventive maintenance is allocated to the dryer in addition to the normal nightly cleanup. The "six-day" processing weeks do not have this additional preventive maintenance period.

This period of preventive maintenance will require labor from both the dryer operator (104) and the powder bagger (108). During this period the dryer will be more completely disassembled than during the regular nightly cleaning and the inside of the various chambers completely cleaned in order to remove all residual powder. During a single such daytime preventive maintenance period a total of approximately seven hours each of class A and B labor is required. Fifty-two weeks in a year would create a total requirement of 364 hours each of class A and B labor if five-day type operations are conducted.

Using labor unit prices assigned in Appendix J, an annual fixed maintenance labor cost can be calculated for the five-day type operations as follows:



$$\begin{aligned}
 364 \text{ hrs. class A} \times \$1.70/\text{hr.} &= \$618.80 \\
 364 \text{ hrs. class B} \times \$1.60/\text{hr.} &= \$582.40 \\
 &\underline{\$1201.20}
 \end{aligned}$$

Since the six-day type operations were defined to be without a mid-week cleanup, no charge for fixed labor maintenance of the dryer was made.

TABLE 13.--Summary of annual fixed labor costs assigned to the model plant

Fixed labor cost element	Cost assigned
Working foreman . . . . .	\$1,440.00
Dryer maintenance:	
Five-day weeks . . . . .	1,201.20
Six-day weeks . . . . .	--
Totals:	
Five-day weeks . . . . .	\$2,641.20
Six-day weeks . . . . .	1,440.00

#### Repairs and maintenance

Data for this expense item were obtained from the accounts of the case study plant. Data for three consecutive years were available and used for the estimates of this section. The total quantities for each of the three accounts were adjusted by using the ratio between the floor area in the model plant and the floor space in the case study plant building.<sup>1</sup> This was an arbitrary allocation and may not have fairly represented the distribution of the expenses among the several departments located in the building.

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<sup>1</sup>See Figure 2 in the technology section of Part III for floor plan of the model plant.

Maintenance labor.---This account included only labor expenses for the services of a plant engineer and his assistants. Maintenance labor was required for the repair of motors and pumps, alterations in the building and equipment, installation of replacement equipment, and maintenance of the building.

Maintenance repairs.---This account included the expense of repairs to the building and minor alterations that were not capitalized. Included were such recurring items as repairs to the roofs and floors, replacement of tiling, and general painting.

General supplies.---This account showed expenses for supplies that were too minor to warrant capitalization. Representative items included piping, black and stainless steel fittings, and some small electrical equipment.

A three-year average for each of these accounts was used in arriving at the \$15,641 annual expense that was assigned to the repairs and maintenance annual fixed cost.

TABLE 14.--Repairs and maintenance expenses from case study plant records allocated to the model plant on the basis of comparative floor space

Expense account	1962	1963	1964	Average
Maintenance labor	\$ 4,741	\$4,731	\$4,514	\$ 4,662
Maintenance repairs	2,840	2,505	6,096	3,814
General supplies	10,648	4,313	6,534	7,165
Total	--	--	--	\$15,641

### Depreciation

Valuation of the physical plant was approached in two different manners. One method used an updating of the valuations shown on the

plant inventory. Price indexes developed by the U.S. Office of Business Economics were used to adjust for changes in building and machinery costs since the items were originally acquired by the plant.<sup>1</sup> Table 15 presents the adjusted values of the plant inventory listed in the categories as carried by the plant.

The second method used for valuing the physical plant was to obtain estimates of the replacement cost for existing case study plant equipment. The C. E. Rogers, Co. cooperated with estimates on the evaporator and associated equipment. The Food Equipment Co. provided an estimate for the dryer and associated equipment. Several other dairy equipment suppliers were contacted for various individual pieces of equipment. Table 15 summarizes these several estimates. The breakdown necessarily is somewhat different from that of Table 38 in Appendix A, which lists all equipment assigned to the model plant.

Costs assigned to the model plant equipment represent a blending of the two methods. Information on each individual item of equipment was evaluated in order to be able to determine the applicability of each method.

Calculation of the cost for the model plant building was made on the basis of the cost for recent construction of a similar building by the case study plant. The total cost of the larger plant construction was adjusted downward to the size allocated to the model plant building by a factor equal to the ratio between the floor space in the two structures. This estimated cost was then adjusted for changes in the relevant Department of Commerce price index since construction.

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<sup>1</sup>U.S. Department of Commerce, Survey of Current Business.



TABLE 15.--Valuation of the model plant inventory and annual depreciation expenses

Item	Adjusted <sup>a</sup> cost	Estimated cost	Assigned cost	Life <sup>b</sup> exp.	Annual deprec.
Evaporator . . . . .	143,247 <sup>c</sup>	123,600 <sup>g</sup>	123,600	12	10,300
Installation expense .	16,820 <sup>c</sup>	--	16,820	12	1,401
Flow meter . . . . .	1,745 <sup>c</sup>	--	1,745	12	145
Hot well . . . . .	--	4,000 <sup>h</sup>	4,000	12	444
Live steam heater . .	--	14,000 <sup>g</sup>	14,000	12	1,167
Holding tube . . . . .	1,914 <sup>c</sup>	--	1,914	12	160
Liquid level controls	2,614 <sup>c</sup>	4,200 <sup>g</sup>	4,200	12	350
Turbidity controls . .	1,197 <sup>c</sup>	2,000 <sup>g</sup>	2,000	12	167
CIP equipment . . . . .	--	1,000 <sup>h</sup>	1,000	12	83
Control center . . . . .	--	2,200 <sup>g</sup>	2,200	12	183
Product removal pump .	2,122 <sup>c</sup>	--	2,122	12	177
Large cooling tower. .	2,412 <sup>c</sup>	--	2,142	12	201
Small cooling tower. .	1,704 <sup>c</sup>	--	1,704	12	142
Dryer . . . . .	155,434 <sup>c</sup>	142,000 <sup>i</sup>	146,099 <sup>m</sup>	12	12,175
Installation expense .	11,214 <sup>c</sup>	--	11,214	12	934
Portable transfer pump	730 <sup>c</sup>	--	730	12	61
Cyclocentric sifter. .	-- <sup>d</sup>	9,335 <sup>i</sup>	9,335	12	778
Control center . . . . .	3,044 <sup>c</sup>	--	3,044	12	254
Miscellaneous:					
Cooling plate . . . . .	6,652 <sup>c</sup>	--	6,652	12	554
Insulated storage vat	6,428 <sup>c</sup>	--	6,428	12	536
Platform scales . . . .	-- <sup>e</sup>	950 <sup>j</sup>	950	12	79
Sewing machine . . . . .	-- <sup>e</sup>	250 <sup>h</sup>	250	12	21
Moisture tester . . . .	-- <sup>e</sup>	300 <sup>h</sup>	300	12	25

TABLE 15.--Continued

Item	Adjusted <sup>a</sup> cost	Estimated cost	Assigned cost	Life <sup>b</sup> exp.	Annual deprec.
Stencil cutter . . . . .	-- <sup>e</sup>	300 <sup>k</sup>	300	12	25
Electric forklift . . .	3,754 <sup>c</sup>	--	3,754	12	313
Forklift battery charger	287 <sup>c</sup>	--	287	12	24
Magnesium loading ramp .	151 <sup>c</sup>	--	151	12	13
Wooden storage pallets .	2,233 <sup>c</sup>	--	2,233	12	186
Building . . . . .	70,000 <sup>f</sup>	--	70,000	45	1,556
Land . . . . .	--	--	--	--	--
Total			\$438,174		\$32,454

<sup>a</sup>The acquisition cost was adjusted for an increase in costs using Department of Commerce price indices as indicated.

<sup>b</sup>U.S. Treasury Department, Depreciation: Guidelines and Rules (Internal Revenue Service Publication No. 456, 1962), pp. 11-12.

<sup>c</sup>Adjusted to November, 1964 using the Machinery and Motive Products price index from Survey of Current Business, U.S. Department of Commerce, Office of Business Statistics.

<sup>d</sup>This equipment is included under "Dryer."

<sup>e</sup>This equipment was used equipment when purchased by the plant and the original cost therefore could not be used to estimate a replacement cost.

<sup>f</sup>Adjusted to October, 1964 using E. H. Boeckh and Assoc., Inc. Construction Indexes, Average 20 Cities, Commercial and Factory Buildings (Brick and Concrete) from the statistical supplement of the Survey of Current Business compiled by the U.S. Office of Business Economics.

<sup>g</sup>FOB shipping point, freight allowed and prepaid. Letter from D. Fishwick, Secretary-Treasurer of C. E. Rogers Company, Detroit, Michigan, January 19, 1965.

<sup>h</sup>Interview with plant accountant and foreman, February 13, 1965.

<sup>i</sup>Includes high pressure feed pump, dryer and redrier burners, all fans, motors and airlocks, and one man for thirty days to assist in assembling the unit at the plant location. FOB shipping point. Letter from Wm. E. Hoyt, Chief Engineer, Food Equipment Corporation, Rockford, Illinois, January 29, 1965.

<sup>j</sup>Letter from Grain Belt Supply Co., Inc., Salina, Kansas, January 18, 1965.

<sup>k</sup>Telephone conversation with Buzzel's Office Supply, Manhattan, Kansas, January 21, 1965.

<sup>m</sup>Adjusted cost (including freight) minus estimated cost of the cyclocentric sifter.

As indicated in the technology section, the evaporator has been assembled through a series of alterations. It was believed that the original inventory cost of the separate units might represent some costs which might not be incurred in a new installation of similar equipment. It was therefore decided to use the recent value estimate rather than the adjusted cost.

The adjusted cost technique was used for the dryer installation and associated equipment. The original installation had been made in a single unit and therefore was not subject to the difficulty encountered with the evaporator. In addition, the inventory cost included freight expense while the estimate did not.

Depreciation was figured using the straight-line method. Life expectancies for the various items of equipment were obtained from the current U.S. Treasury guideline booklet.<sup>1</sup> It was recognized that recent Internal Revenue Service changes in depreciation procedures affect the period of write-off and tend to make investment generally more attractive. No attempt was made, however, to incorporate these innovations into this study. Total depreciation that was considered as an annual fixed cost was \$32,454.

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<sup>1</sup>U.S. Treasury Department, Depreciation: Guidelines and Rules (Internal Revenue Service Publication No. 456; 1962), 11-12.



### Interest

Interest on total plant investment is an annual expense that must be met for the plant. The total inventory cost assigned in Table 15 represents the investment required for a new installation of the model plant. Interest cannot be figured against this entire figure, however, and be applicable after the first year because no allowance would have been made for depreciation.

The depreciation technique presented above assumed a straight-line depreciation for a definite period of time. The average value during the period would then be equal to one half of the initial investment. For the model plant an average investment which could be applied throughout its useful life can therefore be obtained from the \$438,174 inventory cost assigned in Table 15 as \$219,087. Application of the six percent assumed rate of annual interest produces an annual interest charge of \$13,145.

### Property taxes

Property taxes were also calculated on the basis of the inventory costs assigned to the model plant in Table 15. However, since those costs were representative of a new installation, a tax assessment against the full value would not be applicable for the full life of the plant. Assessment was therefore made against one half of the original cost of the plant in the same manner as the interest expense was allocated above.

Assessment of the plant and equipment for tax estimation purposes was made on the basis of the 1963 Kansas average real estate ratio of twenty percent.<sup>1</sup> Application of this figure to one half of the \$438,174

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<sup>1</sup>Kansas, Property Valuation Department, Report of the Real Estate Assessment Ratio Study, State of Kansas (Topeka: 1963), p. 5.

inventory cost assigned in Table 15 results in an assessed taxable valuation of \$43,838. This is an assessment against the valuation of the building and equipment only. No valuation or assessment has been made either against the real estate upon which the building is located or against any powder which might be in storage. The assumption is also made that the building and its contents would be assessed at the same percentage ratio as the real estate would have been if it had been included.

The 1963 average levy on tangible property valuations for all counties in Kansas was 72.0527 mills per dollar.<sup>1</sup> Application of this average levy to the above assessed taxable valuation of the plant building and contents produces a property tax figure of \$3,160.

TABLE 16.--Summary of annual fixed costs allocated to the model plant

Fixed cost element	Cost assigned
Administrative expense . . . . .	\$15,328
Fixed labor:	
Five-day weeks . . . . .	2,641
Six-day weeks . . . . .	1,440
Repairs and maintenance . . . . .	15,641
Depreciation . . . . .	32,454
Interest . . . . .	13,145
Property taxes . . . . .	3,160
Totals:	
Five-day weeks	\$82,369
Six-day weeks	81,168

<sup>1</sup>Kansas, Property Valuation Department, Statistical Report of Property Assessment and Taxation (Topeka: 1963), p. 24.

## V. COSTS OF PRODUCING MILK POWDER

The analysis has thus far been concerned with the measurement and presentation of physical cost element requirements. A set of factor prices will be applied to these physical requirements in this section. The resulting costs will be analyzed with respect to individual proportions, with respect to different types of plant operations, and finally with respect to low-volume drying technology.

### Model Plant Processing Costs

The transition from physical cost element requirements to a statement of requirements in terms of costs will be made in this section.<sup>1</sup> Factor prices will be applied to the physical cost element requirements in the first sub-section. Appropriate formulas from the mathematical model will be used in the second and third sub-sections to develop total processing costs and average total processing costs for the various types of processing defined for the model plant.

#### Application of factor prices to physical cost element requirements

In order to lend flexibility to the findings of this study, direct cost element requirements were presented in physical units in the preceding section. This technique permits use of the same basic physical data

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<sup>1</sup>As was noted in the discussion of the mathematical model in Part II, the change from discussion of physical units to cost units in the literary descriptions will be denoted by use of the terms "cost element requirements" to indicate physical units, and "cost element costs" to indicate cost units.



with many varying combinations of cost element prices. It is the purpose of this section to apply a set of cost element prices to the preceding physical requirements. Techniques that follow can be used with any selected set of prices.

The set of cost element prices that will be applied in this section is developed in Appendix J and summarized in Table 57 of that section. The individual cost element costs of Tables 17, 18, and 19 are obtained by multiplying each direct cost element requirement of Tables 10, 11, and 12 by its respective cost element price.

Following aggregation techniques specified by the mathematical model notations (16) and (17), individual direct cost element costs in Tables 17, 18, and 19 are aggregated over the appropriate stages and summarized for each cost element in Table 20. Finally, appropriate direct cost element costs are aggregated vertically in Table 20 and summarized in Table 21 for each final product using summation notations specified in Table 4.

Included in Table 21 are total annual fixed costs from the preceding section. These costs were stated in monetary terms in Table 16 and require no further calculation or aggregation in this section.

Individual columns of Table 21 correspond to the "a", " $c_1$ ", and " $d_1$ " terms of equations (7) and (8) of the mathematical model. The presentation of these individual terms in Table 21 completes the aggregation of processing costs specified for the model plant by summation notations (9), (10), and (11) of the mathematical model. The following sections will use the "a", " $c_1$ ", and " $d_1$ " values of Table 21 in conjunction with equations (7) and (8) of the mathematical model to calculate and present total processing costs and average total processing costs for the model plant.

TABLE 17.--Fixed direct cost element costs per production run by stages obtained from Table 10 by application of cost element prices

Cost elements	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Class "A" labor . . . . .	\$12.978000	\$ 6.66400	\$0.731000	--	--	--
Class "B" labor . . . . .	--	--	0.656000	--	--	--
Class "C" labor: <sup>a</sup>						
50-lb. bag oper'ns . .	--	--	0.615000	--	--	--
100-lb. bag oper'ns . .	--	--	--	--	--	--
Electricity . . . . .	2.17139579	1.61305065	0.00026406	--	--	--
Natural gas . . . . .	--	1.11196800	--	--	--	--
Steam . . . . .	6.79007576	--	--	--	--	--
Water . . . . .	0.14580000	0.19845000	0.02700000	--	--	--
Chlorine . . . . .	0.91000000	--	--	--	--	--
LC-10 acid . . . . .	4.59000000	--	--	--	--	--
Shur-spray acid . . . .	--	2.24400000	--	--	--	--
Alkali cleaner . . . . .	5.00000000	0.62500000	--	--	--	--
Containers: <sup>a</sup>						
50-lb. plain bags . . .	--	--	--	--	--	--
100-lb. plain bags . .	--	--	--	--	--	--
100-lb. gov't bags . .	--	--	--	--	--	--
Felt roofing paper. . . .	--	--	--	--	--	--
Insecticide . . . . .	--	--	--	--	--	--
Lumber . . . . .	--	--	--	--	--	--
Totals:						
50-lb. plain oper'ns .	\$32.58527155	\$12.45646865	\$2.02926406	--	--	--
100-lb. plain oper'ns .	32.58527155	12.45646865	1.41426406	--	--	--
100-lb. gov't oper'ns .	32.58527155	12.45646865	1.41426406	--	--	--

<sup>a</sup>Only one cost element cost in this category is applicable for each product.



TABLE 18.--Variable direct cost element costs per hundredweight of powder by stages for five-day weeks obtained from Table 11 by application of cost element prices

Cost elements	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Class "A" labor . . . .	\$0.0488244311	\$0.0056929286	\$0.0449184766	--	\$0.0050451612	\$0.0106250000
Class "B" labor . . . .	--	0.0010660958	0.0472666445	--	0.0047483870	0.0100000000
Class "C" labor: <sup>a</sup>						
50-lb. bag oper'ns .	--	0.0009994648	0.0443124792	--	0.0044516128	0.0375000000
100-lb. bag oper'ns .	--	--	--	--	0.0044516128	0.0375000000
Electricity . . . . .	0.0275838384	0.0812706045	0.0001645370	--	--	--
Natural gas . . . . .	--	0.0975192464	--	--	--	--
Steam . . . . .	0.1721743590	--	--	--	--	--
Water . . . . .	--	0.0000276834	--	--	--	--
Chlorine . . . . .	--	--	--	--	--	--
LC-10 acid . . . . .	--	--	--	--	--	--
Shur-spray acid . . . .	--	--	--	--	--	--
Alkali cleaner . . . . .	--	--	--	--	--	--
Containers: <sup>a</sup>						
50-lb. plain bags . .	--	--	0.0274500000	--	--	--
100-lb. plain bags . .	--	--	0.0227750000	--	--	--
100-lb. gov't bags . .	--	--	0.0681800000	--	--	--
Felt roofing paper . .	--	--	--	--	--	0.0043750000
Insecticide . . . . .	--	--	--	--	--	0.0011187500
Lumber . . . . .	--	--	--	--	--	0.0087500000
Totals:						
50-lb. plain oper'ns	\$0.0764082695	\$0.1955760235	\$0.1641121873	--	\$0.0142451610	\$0.0723687500
100-lb. plain oper'ns	0.0764082695	0.1945765587	0.1151247081	--	0.0142451610	0.0723687500
100-lb. gov't oper'ns	0.0764082695	0.1945765587	0.1605297081	--	0.0142451610	0.0723687500

<sup>a</sup>Only one cost element cost in this category is applicable for each product.



TABLE 19.--Variable direct cost element costs per hundredweight of powder by stages for six-day weeks obtained from Table 12 by application of cost element prices

Cost elements	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Class "A" labor . . . .	\$0.0488243112	\$0.0079193225	\$0.049184766	--	\$0.0050451612	\$0.0106250000
Class "B" labor . . . .	--	0.0024630490	0.0472666445	--	0.0047483870	0.0100000000
Class "C" labor: <sup>a</sup>						
50-lb. bag oper'ns . .	--	0.0023091084	0.0443124792	--	0.0044516128	0.0375000000
100-lb. bag oper'ns . .	--	--	--	--	0.0044516128	0.0375000000
Electricity . . . . .	0.0275838384	0.0823417131	0.0001660254	--	--	--
Natural gas . . . . .	--	0.0983694213	--	--	--	--
Steam . . . . .	0.1721743590	--	--	--	--	--
Water . . . . .	--	0.0000591666	--	--	--	--
Chlorine . . . . .	--	--	--	--	--	--
IC-10 acid . . . . .	--	--	--	--	--	--
Shur-spray acid . . . .	--	--	--	--	--	--
Alkali cleaner . . . . .	--	--	--	--	--	--
Containers: <sup>a</sup>						
50-lb. plain bags . . .	--	--	0.0274500000	--	--	--
100-lb. plain bags . . .	--	--	0.0227750000	--	--	--
100-lb. gov't bags . . .	--	--	0.0681800000	--	--	--
Felt roofing paper . . .	--	--	--	--	--	0.0043700000
Insecticide . . . . .	--	--	--	--	--	0.0011187500
Lumber . . . . .	--	--	--	--	--	0.0087500000
Totals:						
50-lb. plain oper'ns	\$0.2485825086	\$0.1934173478	\$0.1641136257	--	\$0.0142451610	\$0.0723637500
100-lb. plain oper'ns	0.2485825086	0.1911082394	0.1151261465	--	0.0142451610	0.0723637500
100-lb. gov't oper'ns	0.2485825086	0.1911082394	0.1605111465	--	0.0142451610	0.0723637500

<sup>a</sup>Only one cost in this category is applicable for each product.

TABLE 20.--Summary of direct cost element costs from Tables 17, 18, and 19

Cost elements	Fixed costs per production run	Variable costs per hundredweight powder			
		Five-day operating weeks		Six-day operating weeks	
		Truck ldg.	RR car ldg.	Truck ldg.	RR car ldg.
Class "A" labor . . . .	\$20.37300000	\$0.1044809975	\$0.1100608363	\$0.11067072715	\$0.1122871103
Class "B" labor . . . .	0.06560000	0.0530811273	0.0583327403	0.0544780805	0.0597296935
Class "C" labor: <sup>a</sup>					
50-lb. bag oper'ns .	0.61500000	0.0497635568	0.0828119440	0.0510732004	0.0841215876
100-lb. bag oper'ns .	--	0.0044516128	0.0375000000	0.0044516128	0.0375000000
Electricity . . . . .	3.78471050	0.1090190299	0.1090190299	0.1100915769	0.1100915769
Natural gas . . . . .	1.11196800	0.0975192464	0.0975192464	0.0983694213	0.0983694213
Steam . . . . .	6.79007576	0.1721743590	0.1721743590	0.1721743590	0.1721743590
Water . . . . .	0.37125000	0.0000276834	0.0000276834	0.0000591666	0.0000591666
Chlorine . . . . .	0.91000000	--	--	--	--
LC-10 acid . . . . .	4.59000000	--	--	--	--
Shur-spray acid . . . .	2.24400000	--	--	--	--
Alkali cleaner . . . . .	5.62500000	--	--	--	--
Containers: <sup>a</sup>					
50-lb. plain bags . .	--	0.0274500000	0.0274500000	0.0274500000	0.0274500000
100-lb. plain bags .	--	0.0227750000	0.0227750000	0.0227750000	0.0227750000
100-lb. gov't bags .	--	0.0681800000	0.0681800000	0.0681800000	0.0681800000
Felt roofing paper . .	--	--	0.0043700000	--	0.0043700000
Insecticide . . . . .	--	--	0.0011187500	--	0.0011187500
Lumber . . . . .	--	--	0.0087500000	--	0.0087500000
Totals:					
50# plain oper'ns . .	\$46.48060426	\$0.6135160003	\$0.6716345893	\$0.6204030762	\$0.6785216652
100# plain oper'ns .	45.86560426	0.5635290563	0.6216476453	0.5691064886	0.6272250776
100# gov't oper'ns .	45.86560426	0.6089340563	0.6670526453	0.6145114886	0.6726300776

<sup>a</sup>Only one cost element cost in this category is applicable for each product.



TABLE 21.--Cost terms for total annual processing cost ( $TC_i$ ) and average total cost ( $ATC_i$ ) formulas (7) and (8) of the mathematical model<sup>a</sup>

Type of processing (i)	Total annual fixed cost (a)	Total fixed operating cost ( $c_i$ )	Variable operating cost ( $d_i$ )
Five-day weeks			
Truck loading			
50-lb. plain	\$82,369	\$46.48060426	\$0.6135160003
100-lb. plain	82,369	45.86560426	0.5635290563
100-lb. gov't	82,369	45.86560426	0.6089340563
RR car loading			
50-lb. plain	82,369	46.48060426	0.6716345893
100-lb. plain	82,369	45.86560426	0.6216476453
100-lb. gov't	82,369	45.86560426	0.6670526453
Six-day weeks			
Truck loading			
50-lb. plain	81,168	46.48060426	0.6204030762
100-lb. plain	81,168	45.86560426	0.5691064886
100-lb. gov't	81,168	45.86560426	0.6145114886
RR car loading			
50-lb. plain	81,168	46.48060426	0.6785216652
100-lb. plain	81,168	45.86560426	0.6272250776
100-lb. gov't	81,168	45.86560426	0.6726300776

<sup>a</sup>These formulas, repeated for reference, are as follows:

$$TC_i = a + c_i X + d_i Z, \text{ and } ATC_i = \frac{a + c_i X}{Z} + d_i.$$

Total and average costs presented in this section represent only these costs incurred in the processing of skim milk into milk powder. It would also be necessary to calculate the expenses incurred during procurement, receiving of the fluid milk, and cream separation in addition to the costs of this section in order to represent overall total cost of the final product.



### Total processing costs

Total processing costs for the model plant defined for this study will be derived by reference to equation (7) of the mathematical model:

$$TC_i = a + c_i X + d_i Z .$$

Values for the "a", "c<sub>i</sub>" and "d<sub>i</sub>" terms were presented in Table 21.

Values for the "X" and "Z" terms remain to be specified.

The annual number of operating days (X) for both the five-day operating weeks that include preventive maintenance, and the six-day operating weeks without preventive maintenance, will be developed for this presentation in the following manner. Each operating year will be assumed to have fifty-two operating weeks. The maximum number of operating days per year for each type of operating week will then be found by applying the weekly definition to the number of weeks in a year. This will yield 260 operating days for the five-day weeks with preventive maintenance, or 312 operating days for the six-day weeks without preventive maintenance.

It will be further assumed that the following holidays will be observed: New Years Day, Memorial Day, Fourth of July, Labor Day, Thanksgiving, and Christmas.<sup>1</sup> These holidays further reduce the maximum possible number of operating days by a total of six days annually.

Total annual powder production will be considered to be variable from a minimum of zero production to some specified maximum production limitation that is to be developed. It was indicated in the technology section that the production of the model plant is limited to the output

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<sup>1</sup>These days will be considered to be holidays without pay for the purposes of this study. However, if any holiday should fall on a Sunday, it will be assumed that the following Monday will be allowed as compensatory time. The analysis could be extended to include a fixed labor charge for selected individuals for these holidays.

of the evaporator and that the output of the evaporator is assumed to be proportional to the length of the evaporator processing period.

The maximum length of the evaporator processing period can therefore be calculated by adjusting the twenty-four hour production run time period for the periods of time assigned to the fixed phases as given in Appendix C. The total production run period required by the fixed phases of the evaporating stage is 11.5833 hours. The maximum production run period remaining that can be used for processing in the evaporating stage is therefore 12.4167 hours per production run or day. Application of the 3,481.8634 pounds of powder per hour average processing rate to the maximum daily processing period produces the 432.3325 hundredweight per day value for Table 22.<sup>1</sup>

Notation (6) of the mathematical model specified that annual powder production was assumed to be equally distributed over total annual operating days (X). When the maximum daily production value is multiplied by the maximum number of operating days the maximum annual powder production values of Table 22 are derived.

TABLE 22.--Maximum annual operating days and powder production specified for the model plant

Type of operating week	Number of operating days (X)	Cwt. of powder production	
		Daily(Y)	Annually(Z)
Five-day . . . . .	254	432.3325	109,812
Six-day . . . . .	306	432.3325	132,294

Total annual processing costs for these two annual production levels are stated in Table 23 for each of the final products. The total

<sup>1</sup>See Table 46 in Appendix E for dryer processing rates.



TABLE 23.---Annual processing costs per hundredweight of powder for the average annual production and the maximum possible levels of annual production for the two processing week definitions

Type of processing	Two-year average production <sup>a</sup>		Maximum possible production <sup>b</sup>	
	Total cost	Average cost	Total cost	Average cost
Five-day weeks				
Truck loading:				
50-lb. plain bags	\$137,072.1122	\$1.9604135043	\$161,546.4925	\$1.4711187530
100-lb. plain bags	133,420.8151	1.9081924355	155,901.1162	1.4197092868
100-lb. gov't bags	136,595.5327	1.9535974355	160,887.1301	1.4651142868
RR car loading:				
50-lb. plain bags	\$141,135.7640	\$2.0185320933	\$167,928.6110	\$1.5292373420
100-lb. plain bags	137,484.4668	1.9663110245	162,283.2347	1.4778278758
100-lb. gov't bags	140,659.1844	2.0117160245	167,269.2486	1.5232328758
Six-day weeks				
Truck loading:				
50-lb. plain bags	\$138,769.6480	\$1.9846917618	\$177,366.6695	\$1.3414566758
100-lb. plain bags	134,994.8006	1.9307036697	170,492.2487	1.2887375747
100-lb. gov't bags	138,169.5182	1.9761086697	176,499.0578	1.3341425747
RR car loading:				
50-lb. plain bags	\$142,833.2997	\$2.0428103508	\$185,055.4101	\$1.3995752648
100-lb. plain bags	139,058.4523	1.9888222587	178,180.9893	1.3468561637
100-lb. gov't bags	142,233.1699	2.0342272587	184,187.7984	1.3922611637

<sup>a</sup>Two-year average production from Table 33: 69,920 cwt.

<sup>b</sup>Maximum possible production from Table 18: 109,812 cwt. for five-day weeks and 132,294 cwt. for six-day weeks.



cost calculation for the average annual production level of powder produced in five-day weeks, bagged in fifty-pound bags and loaded into trucks is illustrated below.

$$\begin{aligned}
 TC_1 &= a + c_1X + d_1Z \\
 &= \$82,369 + (\$46.48060426) (254) + (\$0.6135160003) (69,920) \\
 &= \$137,072.1122 \quad .
 \end{aligned}$$

There are only four possible combinations of the " $a + c_1X$ " term required for the average cost equation calculations presented in Table 23. These four are noted in Table 24 for reference purposes.

TABLE 24.--Values for the " $a + c_1X$ " term of the total annual processing cost formula required for calculation of the total costs presented in Table 23

Type of processing week	Size of powder container	
	50-pound	100-pound
Five-day . . . . .	\$94,175.07348	\$94,018.86348
Six-day . . . . .	95,391.06490	95,202.87490

Total annual processing costs obtained from the total cost formula are indicated for two types of processing in Figure 6. This illustration indicates that total costs are positive for all levels of annual production and increase in proportion to output. These two curves are representative of the total costs for the two types of processing that show either the highest or the lowest total cost at any level of annual production, respectively.

Inspection of the total cost curves of Figure 6 will tend to give the impression that the " $a + c_1X$ " values of Table 24 represent the total annual fixed cost of the model plant that would be experienced at

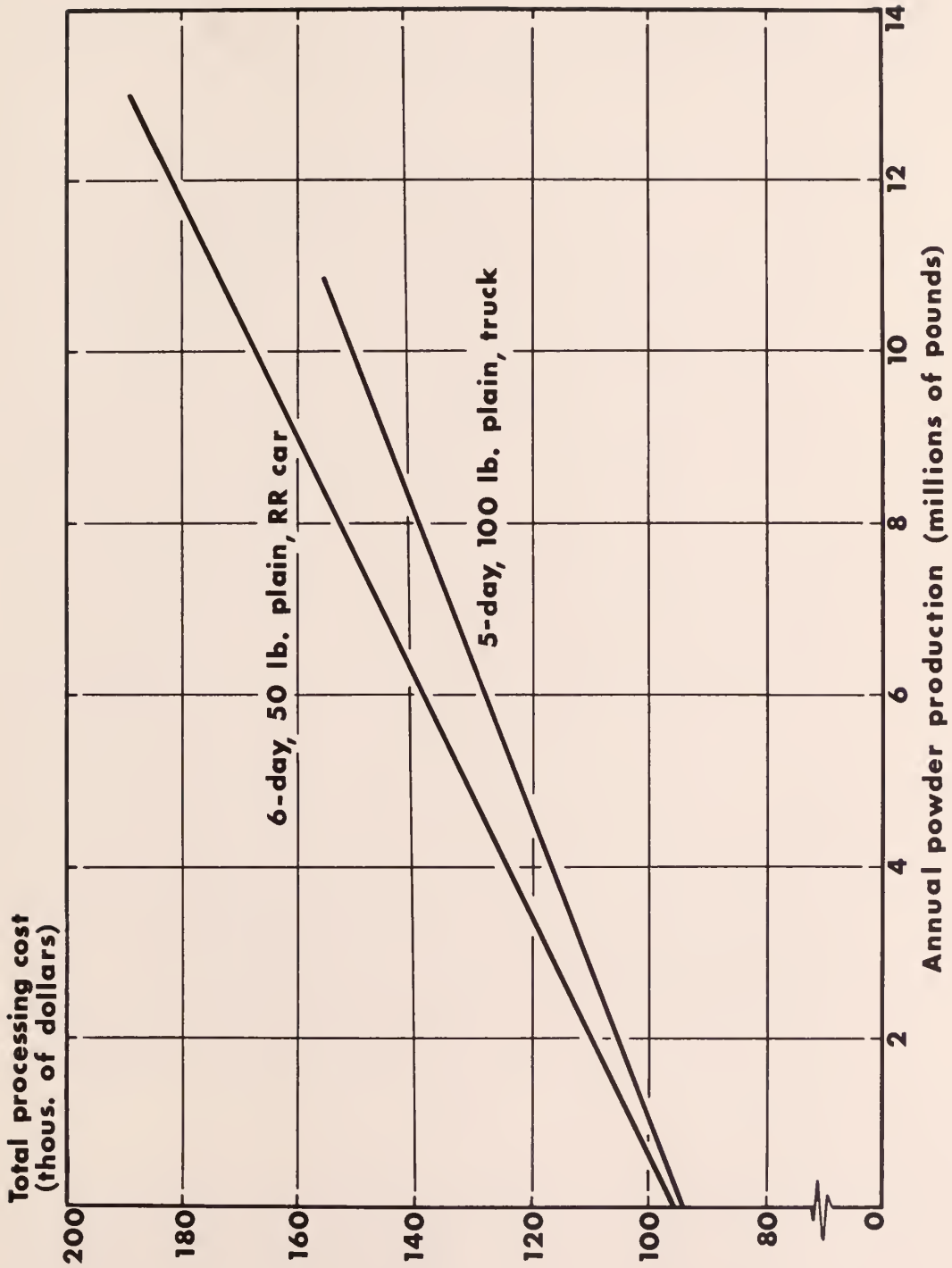


Fig. 6.--Total annual processing costs for the most, and least, efficient types of processing at various levels of annual production within the maximum capacity limitation of the model plant.

zero production. An analysis of implications this interpretation will show it to be erroneous, however, and to be the result of the special limitations under which the total annual cost formula has been defined.

Examination of the individual terms of the total cost formula at zero production may be helpful in the presentation of this analysis. Specifically, it can be seen that with "Z" equal to zero the " $d_1 Z$ " term will be equal to zero and will drop out of the total cost calculation at zero production.

The " $c_1 X$ " term in the total cost calculation is a quasi-fixed cost which varies in proportion to the number of operating days (X). This quasi-fixed cost appears as part of total annual fixed cost in Figure 6 because production has been assumed to be equally divided among a given number of operating periods and the total number of operating periods have been assumed to be equal to (or "fixed" at) the maximum number possible during the annual period. The " $c_1 X$ " term therefore should not be a legitimate part of the annual fixed cost.

Likewise, the "a" term is misleading as a sole indicator of the total annual fixed cost. Included in the "a" term is an allowance for fixed labor required by the weekly preventive maintenance for the dryer. These periods would not be necessary for an annual situation in which no production was attempted.

In summary, the total costs at zero production of Figure 6 and the " $a + c_1 X$ " terms of Table 24 would represent the total annual fixed cost for the model plant only in the highly unlikely situation in which a complete preparation and cleaning of all equipment was performed on each of the maximum number of annual operating days, supplemented by a complete period of preventive maintenance on the dryer, but with no production! The true annual fixed cost for the model plant can only be



obtained by "adjusting" the "a" term for whatever preventive maintenance expense is included for each type of processing. This will result in an annual fixed cost of \$81,168.

Other adjustments of the total cost formula are possible in order to adapt it to varying sets of assumed operating conditions. As was noted in the discussion of Part II, the total annual cost formula is based on three assumptions. These assumptions relate to the number of operating days in a year, the distribution of annual production among these operating periods, and the number of operating weeks in a year. Adjustment of the total cost formula for other assumed values would require substitution of the assumed number of operating periods for the "X" term, and adjustment of the fixed labor charge to reflect the number of assumed processing weeks. Distribution of production among the total number of operating periods, however, will not affect the resulting total cost as long as the total number of operating periods (both daily and weekly) is known.

#### Average total processing costs

Average total processing costs for the model plant defined in this study will be derived by reference to equation (8) of the mathematical model:

$$ATC_1 = \frac{a + c_1 X}{Z} + d_1 .$$

Reference can be made to Tables 21 and 22 for values, of the "a", "c<sub>1</sub>", "d<sub>1</sub>" and "X" terms required. The same table also gives the maximum limitations for the "Z" term, and Table 46 gives the two-year average production level of the case study plant obtained from the plant records.

Table 23 presents the average annual processing costs for each of the final products for both of the "average" and "maximum" values of

annual production (Z). Calculations for the average annual production level of powder produced in five-day weeks, bagged in fifty-pound bags and loaded onto trucks are illustrated below.

$$\begin{aligned}
 ATC_i &= \frac{a + c_i X}{Z} + d_i \\
 &= \frac{\$82,369 + (\$46.48060426)(254)}{69,920} + \$0.6135160003 \\
 &= \$1.9604135043
 \end{aligned}$$

It can be noted that this is the same cost that is obtained by dividing the total cost value from Table 23 by total annual production (Z), as should be expected. Similar to the total cost calculations, there are only four  $\frac{a + c_i X}{Z}$  terms for each assumed level of annual production (Z). These four values are presented for two assumed levels of annual production in Table 25 for reference purposes.

TABLE 25.--Values for the " $\frac{a + c_i X}{Z}$ " term of the average total processing cost formula required for calculation of average total processing costs in Table 23

Type of processing week	Type of powder container			
	Fifty-pound		Hundred-pound	
	Two-year <sup>a</sup> ave. prod.	Maximum <sup>b</sup> production	Two-year <sup>a</sup> ave. prod.	Maximum <sup>b</sup> production
Five-day	\$1.3468975040	\$0.8576027527	\$1.3446633792	\$0.8561802305
Six-day	1.3642886856	0.7210535996	1.3615971811	0.7196310861

<sup>a</sup>Two-year average annual production from Table 46: 69,920 cwt.

<sup>b</sup>Maximum possible annual production figures from Table 22: 109,812 cwt. for five-day weeks; 132,294 cwt. for six-day weeks.

Average total processing costs for selected volumes of powder produced under two sets of conditions are presented in Table 26. These two types of products represent the highest and the lowest average total

processing costs for any given level of production up to the maximum possible for each particular type of production.

This presentation of average total processing costs for the various types of processing is subject to limitations from the same assumptions as were discussed for the presentation of total costs. These limitations can also be removed for the analysis of average costs in the same manner as for total costs.

TABLE 26.--Average total processing costs per hundredweight for the most, and the least, efficient types of production at various levels of annual production within the capacity of the model plant

Annual production level (cwt.)	Type of processing	
	5-day, 100-lb. plain bags in trucks	6-day, 50-lb. plain bags in RR cars
10,000 . . . . .	\$9.9654	\$10.2176
20,000 . . . . .	5.2645	5.4481
40,000 . . . . .	2.9140	3.0633
60,000 . . . . .	2.1305	2.2684
69,920 . . . . .	1.9082	2.0428
80,000 . . . . .	1.7388	1.8709
100,000 . . . . .	1.5037	1.6324
109,812 . . . . .	1.4197	1.5472
120,000 . . . . .	-- <sup>a</sup>	1.4734
132,294 . . . . .	-- <sup>a</sup>	1.3996

<sup>a</sup>Beyond the model plant production capacity for this type of processing.

Average total processing costs of Table 26 are presented graphically in Figure 7. These two curves are but two of the twelve curves which could be presented for types of processing which have been defined



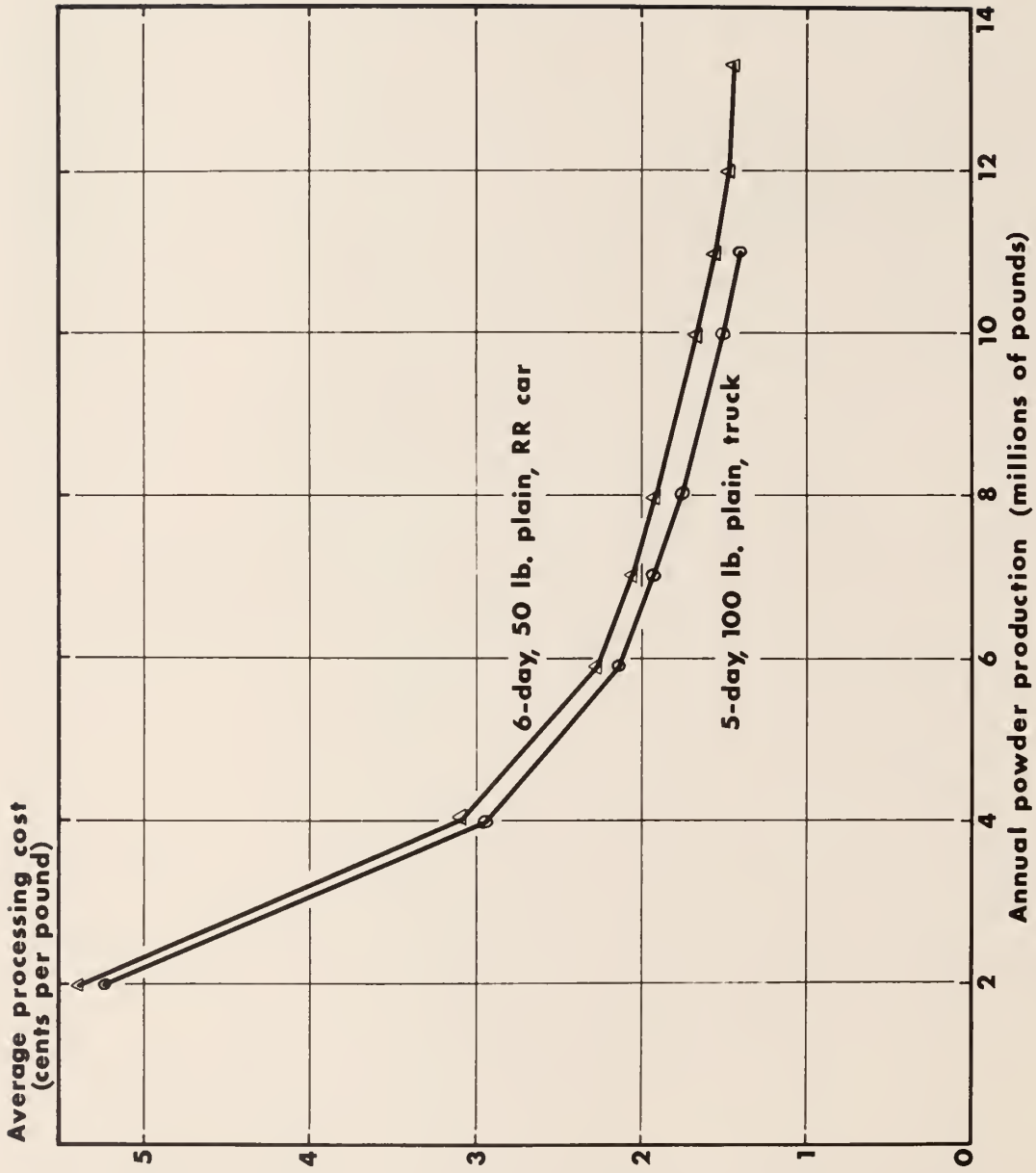


Fig. 7.--Average processing costs per hundredweight for the most, and least, efficient types of processing at various levels of annual production within the maximum capacity limitation of the model plant.

for the model plant. Each curve is a short run average cost (SRAC) curve for a fixed plant and technology with the reservations that the cost of the skim milk input is not included, and that variations in output are obtained solely through variations in length of the processing periods and not through variations in the basic processing rates.

The remaining ten average processing cost curves would lie between these two curves and would be shaped similarly throughout the ranges of annual production. The remaining SRAC curves will not be presented.

### Analysis of the Model Plant Processing Costs

#### Average total processing cost element proportions

The average total processing costs of Table 23 can be examined in order to ascertain the proportional contribution of each individual cost element. This analysis will be presented for three different types of processing and will refer to the two-year average level of annual production obtained from case study plant records.

Two of the types of processing presented will be those which show the highest average cost (6-day, 50-lb. plain bags, RR car loading), and the lowest average cost (5-day, 100-lb. plain bags, truck loading) for all combinations of processing by the model plant at this level of production. However, the case study plant did not use the type of processing associated with the highest average cost.<sup>1</sup> The third type of processing that will be presented will therefore be that type used by the case study plant for which average cost is highest (6-day, 100-lb. gov't bags, RR car loading).

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<sup>1</sup>See Table 8 of Part III for a summary of the types of processing practiced in the case study plant.

Individual cost element costs were selected from Tables 16 and 20 for the following analysis.<sup>1</sup> The average cost element cost per unit of product was then calculated for each of these individual cost element costs in the same manner that was used for average cost calculations with the aggregate of all cost element costs. Each cost element cost calculated in this manner will represent its net contribution to average total processing cost. The sum of all cost element costs for a particular product will equal the average total processing cost as calculated for Table 23. The "unaggregated calculation" technique will be described for each economic cost category in turn.

Fixed annual costs.--The fixed annual cost element costs are selected from Table 16 for each type of processing and are collectively represented by the "a" term of the mathematical model. The necessary "unaggregated calculation" for this section can be indicated by reference to equations (8) and (9) of the mathematical model:

$$\begin{aligned} ATC_i &= \frac{a + c_i X}{Z} + d_i \\ &= \frac{a}{Z} + \frac{c_i X}{Z} + d_i \end{aligned} \quad (8)$$

where:

$$a = \sum_{i=1}^6 A_i \quad (9)$$

then:

$$ATC_i = \frac{\sum_{i=1}^6 A_i}{Z} + \frac{c_i X}{Z} + d_i .$$

---

<sup>1</sup>All costs will be rounded to five decimal places for this analysis.



The individual unaggregated average fixed annual cost element costs will be calculated for this analysis by dividing each individual cost from Table 16 ( $A_i$ , where  $i = 1, 2, 3, 4, 5, 6$ ) by the annual powder production level ( $Z$ ) selected. The production level ( $Z$ ) associated with the two-year average processing cost of Table 23 is 69,920 hundredweight.<sup>1</sup>

Fixed production run costs.--The fixed production run cost element costs are selected from Table 20 and are collectively represented by the " $c_i$ " term of the mathematical model. The "unaggregated calculations" required for this section are again obtained by reference to equation (8) of the model in combination with equation (10):

$$\begin{aligned} ATC_i &= \frac{a + c_i X}{Z} + d_i \\ &= \frac{a}{Z} + \frac{c_i X}{Z} + d_i \\ &= \frac{a}{Z} + c_i \left( \frac{X}{Z} \right) + d_i \end{aligned} \quad (8)$$

where:

$$c_i = \sum_{j=1}^{17} \sum_{k=1}^6 \sum_{m=1}^5 P_j \lambda_{jkm} \quad .^2 \quad (10)$$

then:

$$ATC_i = \frac{a}{Z} + \left( \sum_{j=1}^{17} \sum_{k=1}^6 \sum_{m=1}^5 P_j \lambda_{jkm} \right) \left( \frac{X}{Z} \right) + d_i$$

The individual unaggregated fixed production run cost element costs

$\left( \sum_{k=1}^6 \sum_{m=1}^5 P_j \lambda_{jkm}, \text{ where } j = 1, 2, \dots, 17 \right)$  will be calculated by

<sup>1</sup>See Table 46 in Appendix E.

<sup>2</sup>Subject to the restrictions of Table 4 in Part II.

being multiplied by the quotient of the number of annual operating days (X), divided by the annual production level (Z). Only two quotient values are required for the calculations of this analysis. The annual production level is the same for all three types of processing that are being compared (Z = 69,920 cwt.). The number of annual operating days, however, are greater for the six-day weeks (X = 306), than for the five-day weeks (X = 254). The two quotient values (X/Z) that are required for calculations are presented in Table 27 and are referred to as "calculation factors."

TABLE 27.--Unaggregated fixed production run cost element average cost calculation factors (X/Z)

Type of processing week	Calculation factors (X/Z)
Five-day weeks . . . . .	0.00363272
Six-day weeks . . . . .	0.00437643

Variable production run costs.--The variable production run cost element costs are selected from Table 20 and are collectively represented by the " $d_i$ " term of the mathematical model. The technique for the required "unaggregated calculation" of the " $d_i$ " terms is obtained by reference to equations (8) and (11) of the mathematical model:

$$ATC_i = \frac{a + c_i X}{Z} + d_i \quad (8)$$

where:

$$d_i = \sum_{j=1}^{17} \sum_{k=1}^6 \sum_{m=6}^9 P_j \lambda_{jkm}^1 \quad (11)$$

---

<sup>1</sup>Subject to the restrictions of Table 4 in Part II.

then:

$$ATC_1 = \frac{a + c_1 X}{Z} + \left( \sum_{j=1}^{17} \sum_{k=1}^6 \sum_{m=6}^9 P_j \lambda_{jkm} \right) .$$

This notation indicates that the individual variable cost element costs

$\left( \sum_{k=1}^6 \sum_{m=6}^9 P_j \lambda_{jkm}, \text{ where } j = 1, 2, \dots, 17 \right)$  will not require any further

calculation for the analysis of this section.

Each of the individual unaggregated cost element average costs, calculated in the manner indicated above, is presented in Table 28. The percentage relationship of each individual unaggregated cost element average cost, as compared to average total processing cost, was computed for each of the three selected types of processing at 69,920 hundredweight of annual powder production. These proportions, or percentages, are presented in the "proportion" columns of Table 28.

Average costs for certain of the unaggregated cost elements can also be combined into a selective aggregation for further analysis and comparison. Such selective aggregation is shown in Table 29 for combinations of total labor (including fixed annual labor), total utilities, and total supplies. Also shown in Table 29 are the totals of the various individual unaggregated average cost element costs for each type of processing being considered. A comparison of these sums with the average total processing costs from Table 23 indicates that the two methods of cost calculation are virtually identical after allowance for rounding errors.

Examination of Tables 20, 28, and 29 indicates some of the changes that may be observed in both absolute amounts and in various cost proportions when the different types of processing are compared. In general, three types of processing cost comparisons can be made for each



TABLE 28.--Proportional relationships of cost element costs to average total processing cost per hundredweight for an annual powder production of 69,920 hundredweight

Cost element	5-day, 100-lb. plain, truck	
	Cost	Proportion
<b>Fixed annual costs:</b>		
Administrative expense	\$0.21922	0.11488
<b>Fixed labor:</b>		
Foreman . . . . .	0.02060	0.01080
Dryer P.M. . . . .	0.01718	0.00900
Repairs and maintenance . . . . .	0.22370	0.11723
Depreciation . . . . .	0.46416	0.24325
Interest . . . . .	0.18800	0.09852
Property taxes . . . . .	0.04520	0.02369
Total	\$1.17806	0.61737
<b>Fixed production run costs:</b>		
<b>Labor:</b>		
Class A . . . . .	\$0.07401	0.03878
Class B . . . . .	0.00024	0.00013
Class C . . . . .		
<b>Utilities:</b>		
Electricity . . . . .	0.01375	0.00721
Natural gas . . . . .	0.00404	0.00212
Steam . . . . .	0.02467	0.01293
Water . . . . .	0.00135	0.00071
<b>Supplies:</b>		
XY-12 chlorine . . . . .	0.00331	0.00174
LC-10 acid . . . . .	0.01667	0.00874
Shur-spray acid . . . . .	0.00815	0.00427
HC-90 alkali . . . . .	0.02043	0.01071
Total	\$0.16662	0.08732
<b>Variable production run costs:</b>		
<b>Labor:</b>		
Class A . . . . .	\$0.10448	0.05475
Class B . . . . .	0.05308	0.02782
Class C . . . . .	0.00445	0.00233
<b>Utilities:</b>		
Electricity . . . . .	0.10902	0.05713
Natural gas . . . . .	0.09752	0.05111
Steam . . . . .	0.17217	0.09023
Water . . . . .	0.00003	0.00002
<b>Supplies:</b>		
50-lb. plain bags . . . . .	--	--
100-lb. plain bags . . . . .	0.02278	0.01194
100-lb. gov't bags . . . . .	--	--
Felt roofing paper . . . . .	--	--
Malathion insecticide . . . . .	--	--
1x4 pine lumber . . . . .	--	--
Total	\$0.56353	0.29532
Total cost element cost <sup>a</sup>	\$1.90819	--

<sup>a</sup>"Proportion" calculations with Table 23 values to five places.

TABLE 28.--Continued

6-day, 100-lb. gov't, RR car		6-day, 50-lb. plain, RR car	
Cost	Proportion	Cost	Proportion
\$0.21922	0.10777	\$0.21922	0.10731
0.02060	0.01013	0.02060	0.01008
0.22370	0.10997	0.22370	0.10951
0.46416	0.22818	0.46416	0.22722
0.18800	0.09242	0.18800	0.09203
0.04520	0.02222	0.04520	0.02213
<u>\$1.16088</u>	0.57067	<u>\$1.16088</u>	0.56828
\$0.08916	0.04383	\$0.08916	0.04365
0.00029	0.00014	0.00029	0.00014
		0.00269	0.00132
0.01656	0.00814	0.01656	0.00811
0.00487	0.00239	0.00487	0.00238
0.02972	0.01461	0.02972	0.01455
0.00162	0.00080	0.00162	0.00079
0.00398	0.00196	0.00398	0.00195
0.02009	0.00988	0.02009	0.00983
0.00982	0.00483	0.00982	0.00481
0.02462	0.01210	0.02462	0.01205
<u>\$0.19973</u>	0.09818	<u>\$0.20342</u>	0.09958
\$0.11229	0.05520	\$0.11229	0.05497
0.05973	0.02936	0.05973	0.02924
0.03750	0.01843	0.08412	0.04118
0.11009	0.05412	0.11009	0.05389
0.09837	0.04836	0.09837	0.04815
0.17217	0.08464	0.17217	0.08428
0.00006	0.00003	0.00006	0.00003
--	--	0.02745	0.01344
--	--	--	--
0.06818	0.03352	--	--
0.00437	0.00215	0.00437	0.00214
0.00112	0.00055	0.00112	0.00055
0.00875	0.00430	0.00875	0.00428
<u>\$0.67263</u>	0.33066	<u>\$0.67852</u>	0.33215
<u>\$2.03423</u>	--	<u>\$2.04281</u>	--



of the cost categories to be considered. Cost comparisons can be made for five-day versus six-day processing, for truck loading versus railroad car loading operations, and for fifty-pound plain bag operations versus either hundred-pound plain bag or hundred-pound government specification bag operations.

Cost categories for which these comparisons are to be made will be of two general types. The economic definitions for annual fixed costs, fixed production run costs, and variable production run costs constitute the first category. The second category to be considered will be the selective cost element cost aggregations for "total labor," "total utilities," and "total supplies."<sup>1</sup> Changes in the individual cost category items, when comparing types of processing, can be in terms of absolute quantities, in terms of proportions, or both.

The average costs that are presented under the economic definition of "annual fixed costs" show variations in absolute quantity when types of processing weeks are compared. They do not show variation for comparisons of transportation modes or container types. The factor influencing this variation noted between types of processing weeks can be traced to the "fixed labor" requirements presented in Table 16. Preventive maintenance (P.M.) labor requirements amount to \$1,201 annually during five-day week annual periods but are zero by definition during six-day weeks. This amount accounts for all variation in average annual fixed costs noted in Table 29.<sup>2</sup>

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<sup>1</sup>Other combinations of cost elements could also have been aggregated and analyzed in much the same manner.

<sup>2</sup>For example:  $\$1,201/69,920 = \$0.01718$ ; and  $\$1.17806 - \$1.16088 = \$0.01718$ .



TABLE 29.---Comparison of cost element cost relationships for selected cost element classifications

Cost elements	5-day, 100-lb. plain, truck		6-day, 100-lb. gov't, RR car		6-day, 50-lb. plain, RR car	
	Cost	Proportion	Cost	Proportion	Cost	Proportion
<b>Fixed annual costs:</b>						
Admin. expense . . . . .	\$0.21922	0.11488	\$0.21922	0.10777	\$0.21922	0.10731
Fixed labor . . . . .	0.03778	0.01980	0.02060	0.01013	0.02060	0.01008
Repairs and maintenance . . . . .	0.22370	0.11723	0.22370	0.10997	0.22370	0.10951
Depreciation . . . . .	0.46416	0.24325	0.46416	0.22818	0.46416	0.22722
Interest . . . . .	0.18800	0.09852	0.18800	0.09242	0.18800	0.09203
Property taxes . . . . .	0.04520	0.02369	0.04520	0.02222	0.04520	0.02213
Total	\$1.17806	0.61737	\$1.16088	0.57067	\$1.16088	0.56828
<b>Fixed production run costs:</b>						
Labor . . . . .	\$0.07425	0.03891	\$0.08945	0.04397	\$0.09214	0.04510
Utilities . . . . .	0.04381	0.02296	0.05177	0.02545	0.05277	0.02583
Supplies . . . . .	0.04856	0.02545	0.05851	0.02876	0.05851	0.02864
Total	\$0.16662	0.08732	\$0.19973	0.09818	\$0.20342	0.09958
<b>Variable production run costs:</b>						
Labor . . . . .	\$0.16201	0.08490	\$0.20952	0.10300	\$0.25614	0.12539
Utilities . . . . .	0.37874	0.19848	0.38069	0.18714	0.38069	0.18636
Supplies . . . . .	0.02278	0.01194	0.08242	0.04052	0.04169	0.02041
Total	\$0.56353	0.29532	\$0.67263	0.33066	\$0.67852	0.33215
Total labor <sup>a</sup> . . . . .	\$0.27404	0.14361	\$0.31954	0.15708	\$0.36888	0.18058
Total utilities . . . . .	0.42255	0.22144	0.43246	0.21259	0.43346	0.21219
Total supplies . . . . .	0.07134	0.03739	0.14093	0.06928	0.10020	0.04905
Overall total	\$1.90821	1.00004	\$2.03424	1.00003	\$2.04282	1.00001
Average processing cost <sup>b</sup>	\$1.90819		\$2.03423		\$2.04281	

<sup>a</sup>Including "fixed labor."<sup>b</sup>Values from Table 23, rounded to five decimal places, were used for "proportion" column calculations.

A comparison of costs that are "fixed for a production run" indicates considerable variation for the two types of processing weeks. This variation can be traced principally to the number of operating days (X) that have been defined for the annual period for each of the two types of processing weeks.<sup>1</sup> With two hundred fifty-four operating days for the five-day weeks, and three hundred six operating days for the six-day weeks, a considerable variation in average costs is introduced by the "X/Z" calculation factors. Another source of variation can be noticed in the comparison of different types of containers. This variation can be traced to the different class C labor requirements stated in Table 20 for fifty-pound bag operations as compared to hundred-pound bag operations. There are no variations to be noted for comparison of the two types of transportation in this cost category.

There is a considerable variation in the "variable costs for a production run" with both complementary and offsetting interactions among the various factors. First, each of the variable cost element costs for six-day weeks exceeds that same cost element cost for five-day weeks, all other things being equal.<sup>2</sup> This can be traced to the effects of the dryer down time expenses incorporated into the analyses of Appendices G and H.

Second, variations noted in a comparison of container types are due to two general factors. There is a difference in the class C labor requirement for fifty-pound bag operations as compared to the hundred-pound bag operations. There are also variations in the costs of all

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<sup>1</sup>See Table 22 for presentation of annual operating day definitions.

<sup>2</sup>Comparing, for example, powder in fifty-pound, plain bags loaded onto a truck during five-day weeks with the same conditions for six-day weeks. Reference to the variable cost terms of Table 21 is helpful at this point.



three types of containers (i.e., fifty-pound plain, hundred-pound plain, and hundred-pound government specification).

Third, variations noted when types of transportation are compared may be traced to two general sources. The labor requirement is much higher for railroad car loading. Also of considerable importance is the fact that no supplies are required for truck loading while this is a sizeable item for railroad car loading.

Another broad type of cost element analysis can be made for which Table 29 is particularly helpful. Aggregation of the individual cost element costs has been made for the three general areas of total labor, total utilities, and total supplies. The presentation of Table 29 permits percentage comparison of these aggregate cost element costs to total average processing cost.

There are certain conclusions that can be drawn from the comparisons of the aggregate costs of various cost elements. In particular there are generalizations that can be made for comparison of the lower average cost types of processing to the higher average cost types. First, fixed annual costs are both a smaller absolute quantity and a smaller proportion of total average cost for the higher cost types of processing.

Second, fixed production run costs are both larger in absolute quantity and in relative proportion for the higher cost types of processing. Third, variable production run costs are both greater in absolute quantity and in relative proportion for the higher cost types of processing.

Fourth, the aggregate quantities for both total labor and total utilities show increases in cost and relative proportion for the higher cost types of processing. The total supply aggregate is also somewhat



larger for the higher cost processing but shows much more variation than do the other cost categories.

As a general conclusion, it would appear that the higher cost types of processing involve increases in the absolute cost quantities for many cost elements. The increases are not proportionate, however, and there is a general increase in the influence of the fixed and the variable costs for a production run over the fixed annual costs for the higher cost processing. In particular, total labor and total utilities exercise proportionately larger influences. Increases in the costs of total supplies are a material factor only for railroad car loading types of operations.

#### Analysis of preventive maintenance expenditures

The labor requirement for the weekly preventive maintenance of the dryer has been defined to constitute an annual fixed expense. This fixed annual labor expense is reduced when preventive maintenance is not performed but the variable expenses of processing are increased due to the expenses incurred during the subsequently more frequent production run stoppages.

Three questions can be framed to aid in the analysis of these preventive maintenance expenditures:

1. Do the preventive maintenance expenditures appear to be recouped by the model plant when operating at the case study plant two-year average volume?
2. What volume of production by the model plant would be required in order to recoup the assumed level of preventive maintenance expenditures?

3. What maximum level of preventive maintenance expenditures could be recouped by the model plant at either the case study plant two-year average volume of production or at the maximum possible volume of production assumed for the model plant?

Each question will be examined in reference to the processing costs that have been established for the model plant in this study. The answers to these questions will necessarily be subject to the assumptions which have been made for this study and may be inaccurate to the extent that these assumptions are inappropriate.

Profitability of past levels of case study plant preventive maintenance expenditures.--It is not possible to directly compare the processing expenses of periods containing preventive maintenance with expenses for periods not containing preventive maintenance. This is true because the annual expenses for each type of operation are based upon a different assumed number of processing days for the cost formula and therefore contain different amounts of "fixed" production run costs.

The five-day processing weeks were considered to contain one day per week which was devoted to dryer preventive maintenance and which did not involve any fixed production run expenses. By comparison, although the six-day weeks did not involve weekly dryer preventive maintenance expenses, they did contain an additional production run and the fixed expenses associated with it. The total fixed production run expenses of the six-day weeks for a one-week period will therefore exceed those of the five-day weeks for the same quantity of production since the fixed expenses associated with a production run (approximately \$46) considerably exceed the expenses of a single dryer preventive maintenance period (approximately \$23). This study has assumed that a period of a week, or a year, is to



contain the maximum number of production runs consistent with the definitions of either five-day or six-day weeks. The average processing cost of any particular volume of powder will therefore be greater for the six-day periods than for the five-day periods.

In order to answer the questions that have been posed, it will therefore be necessary to consider the average processing expenses for powder produced during the same number of production runs for periods with and without preventive maintenance. As an example, the average processing expenses for powder in fifty-pound, plain bags and loaded onto trucks can be compared for processing with, and without, preventive maintenance for a period of one processing year. Both types of processing will be defined to contain two-hundred fifty-four production runs for the present analysis. The remaining fifty-two potential working days will be allocated differently for the two periods, however.

The periods which are considered to contain dryer preventive maintenance will use seven hours of each of the remaining fifty-two days in the year for conducting the preventive maintenance periods once a week. No processing will be assumed to occur during the remaining period of each of these processing days in which a preventive maintenance period occurs. This definition is the same as was used for the five-day processing costs that were presented above in Table 23.

For periods in which no preventive maintenance is assumed to occur, it will be assumed that neither will there be any processing. The average cost calculation for this definition differs from that which was used for six-day week costs in Table 23 only in that the value "254" is used for the "X" term of the "ATC<sub>1</sub>" equation instead of "306."

A comparison of average processing costs for two-year average volumes of powder for the twelve types of processing operations and the



above assumptions is presented in Table 30. Average processing costs for periods including preventive maintenance are higher in every case at this volume. The model plant would therefore not be able to recoup the assumed level of preventive maintenance expenditures when operating at the two-year average level of annual production.

TABLE 30.--Average total processing costs per hundredweight at 69,920 hundredweight of powder per year comparing processing periods identical except for preventive maintenance

Type of processing	Degree of preventive maintenance	
	Weekly preventive maintenance	No preventive maintenance
Truck loading		
50-lb. plain . . . . .	\$1.9604135043	\$1.9501238067
100-lb. plain . . . . .	1.9081924355	1.8965930944
100-lb. govt. . . . .	1.9535974355	1.9419980944
RR car loading		
50-lb. plain . . . . .	\$2.0185320933	\$2.0082423957
100-lb. plain . . . . .	1.9663110245	1.9547116834
100-lb. govt. . . . .	2.0117160245	2.0001166834

Break-even volumes of production for past levels of case study plant preventive maintenance expenditures.--Analysis of the second question can proceed on the same assumptions as were used for costs presented in Table 30. Comparison of processing costs for each type of processing can be made at successively increasing annual volumes of production. Such a comparison for powder processed in fifty-pound plain bags and loaded onto trucks during processing with and without preventive maintenance is presented in Table 31.

TABLE 31.--Effect of model plant preventive maintenance upon average total processing costs per hundredweight of powder in fifty-pound bags, loaded onto trucks and produced during 254 production runs

Annual production level (cwt.)	Degree of preventive maintenance	
	Weekly preventive maintenance	No preventive maintenance
20,000 . . . . .	\$5.3222696743	\$5.2691067503
40,000 . . . . .	2.9678928373	2.9447549132
60,000 . . . . .	2.1831005583	2.1699709675
69,920 . . . . .	1.9604135043	1.9501238067
80,000 . . . . .	1.7907044188	1.7825789947
100,000 . . . . .	1.5552667351	1.5501438110
109,812 . . . . .		
120,000 . . . . .	1.3983082793	1.3951870218
132,294 . . . . .	1.3253780158	1.3231868266
140,000 . . . . .	1.2861950965	1.2845036010
160,000 . . . . .	1.2021102095	1.2014910354
174,385 . . . . .	1.1535571361	1.1535571518
180,000 . . . . .	1.1367108529	1.1369257066
200,000 . . . . .	1.0843913677	1.0852734436

The cost comparison in Table 31 indicates that average processing costs for processing with and without preventive maintenance continue to become closer as the model plant approaches its annual production limitation of 109,812 hundredweight per year. It is not until an annual production level of 174,385 hundredweight is reached, however, that the initial added expenses of the preventive maintenance periods are completely



offset by the greater variable expenses of processing without the preventive maintenance periods.

The break-even point does not occur at the same volume for all types of processing. The critical factor in determining the break-even volume of production is the difference between variable costs for the two types of operations. This difference will be the amount by which initial preventive maintenance expenses are overcome by higher processing costs with each additional hundredweight of annual powder production.

The variable processing costs have been denoted previously by the term " $d_1$ ". This notation can be continued and expanded to specify the notation " $d_{15}$ " for the variable cost term of periods in which preventive maintenance is performed, and " $d_{16}$ " for periods in which no preventive maintenance is performed. The difference between the variable costs for the two types of periods and the 1<sup>st</sup> type of processing can be indicated by the notation " $d_{16} - d_{15}$ ," where " $d_{16}$ " is greater than " $d_{15}$ ". A summary of the values expressing these differences is presented in Table 32 for each type of processing.

TABLE 32.--Differences ( $d_{16} - d_{15}$ ) between model plant variable costs per hundredweight for operations with and without preventive maintenance

Type of container	Type of transportation	
	Truck	Railroad car
50-lb. plain . . . . .	\$0.0068870750	\$0.0068870759
100-lb. plain . . . . .	0.0055774323	0.0055774323
100-lb. gov't . . . . .	0.0055774323	0.0055774323

Break-even annual volume of production (Z) for the amount of preventive maintenance expense specified for the model plant can be found



in the following manner:

$$Z = \frac{\$1,201.00}{(d_{16} - d_{15})} \quad (1)$$

Table 33 presents a summary of these break-even volumes for each type of processing. In each case the required volume lies beyond the capacity of the model plant by an appreciable degree.

TABLE 33.--Annual model plant production break-even points for processing similar except for preventive maintenance expenditures

Type of container	Type of transportation	
	Truck	Railroad car
(in hundredweight)		
50-lb. plain . . . .	174,385	174,385
100-lb. plain . . .	215,332	215,332
100-lb. gov't . . .	215,332	215,332

Recoverable preventive maintenance expenditures at various levels of model plant production.--Relationship (1) from above can also be used to determine the maximum weekly dryer preventive maintenance (P.M.) expenditure that can be recovered at any given volume of annual production. The general relationship that is required will be as follows:

$$\text{Weekly P.M.} = \frac{Z (d_{16} - d_{15})}{52} \quad (2)$$

Relationship (2) can be used to determine the maximum quantity of dryer preventive maintenance expenditure which can be recovered by the model plant operating at the maximum level of production ( $Z = 109,812$  cwt.).

Table 34 summarizes these maximum preventive maintenance expenditures and also presents the preventive maintenance periods in terms of hours per period of preventive maintenance. This additional subdivision is made on the basis of the following assumptions:

1. One each of class A and B labor will be required during dryer preventive maintenance,
2. Each man will be required for the entire duration of the preventive maintenance period.
3. Wage rates will be the same as specified in Table 57 of Appendix J, for a total hourly preventive maintenance charge of \$3.30, and
4. No other expenses will be incurred during the preventive maintenance period.

Values in Table 34 are valid only for this set of assumptions although the same analytical technique could be applied to other sets of assumptions.

TABLE 34.--Recoverable weekly model plant preventive maintenance expenditures for an annual production (Z) of 109,812 hundredweight and fifty-two annual preventive maintenance periods

Type of container	Type of transportation			
	Truck		Railroad car	
	Annual cost	Hours per P.M.	Annual cost	Hours per P.M.
50-lb. plain . . .	\$756.28	4.41	\$756.28	4.41
100-lb. plain . .	612.47	3.57	612.47	3.57
100-lb. gov't . .	612.47	3.57	612.47	3.57

### Profitability of model plant processing operations

The description of technology and presentation of average processing costs for the model plant can be utilized for an analysis of model plant profitability considerations. The following discussion will include consideration of prices for skim milk inputs and powder outputs but will be confined to general notation only and will not consider specific price situations. After statement of general profitability conditions for the model plant a brief discussion will indicate the analytical technique that would be applied to questions of net profitability, break-even volumes of production under given price conditions, and break-even price relationships for given volumes of production.

It should be pointed out that the definitions of costs and profits in the discussion to follow will, of necessity, be somewhat equivocal. This reservation is prompted by the somewhat arbitrary nature in which certain fixed costs have previously been defined for this study.

General profitability conditions.--General profitability analysis can proceed either upon the basis of total costs and revenues or upon average costs and revenues. Use of average cost and revenue terms will necessitate calculation of a physical input-output relationship for quantities of skim milk and dry milk powder processed by the model plant. Such a relationship has been developed in Appendix E stating the pounds of skim necessary for production of each pound of powder. From case study plant production records this skim-to-powder conversion ratio was determined to be approximately equal to 11.2 pounds of skim milk required per pound of powder (11.2:1). This input-output relationship (K) will permit statement of skim milk input costs per unit of powder output. It is also useful for stating the functional relationship between skim milk



input and powder output at a specified level of annual powder production for total cost and revenue statements.

First, general profitability conditions for annual operation of the model plant will be stated in terms of total costs and revenues. Given a set of cost element prices, an input price per unit of skim milk, an output price per unit of dry milk powder, and applicability of assumptions made in this study, total annual revenue for the model must be equal to or greater than total costs in order for model plant operation to be profitable:

$$\text{Total revenue} \geq \text{Total cost} \quad (1)$$

$$(Z) \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) \geq \left( \frac{\text{Total skim}}{\text{input}} \right) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + TC_1 \quad (2)$$

where:

$Z$  = annual powder production level, and

$TC_1$  = total annual processing cost for the 1<sup>st</sup> annual production level ( $Z$ ).

Total skim input is functionally related to the physical quantity of powder output ( $Z$ ) and this relationship is denoted by the term " $K$ " which is approximately equal to 11.2:1. Relationship (2) can therefore be restated as follows:

$$(Z) \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) \geq (K) (Z) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + TC_1 \quad (3)$$

where:

$$\frac{\text{Total skim}}{\text{input}} = (K) (Z) .$$

Alternatively, general profitability conditions for annual operation can be stated in terms of average costs and revenues. Average total revenue per unit of powder must equal or exceed average total cost per unit of powder at the  $Z^{\text{th}}$  annual production level:

$$\frac{\text{Average total revenue}}{\text{Cwt. powder}} \geq \frac{\text{Average total cost}}{\text{Cwt. powder}} \quad (4)$$

$$\frac{\text{Output price}}{\text{Cwt. powder}} \geq \frac{\text{Input cost}}{\text{Cwt. powder}} + \frac{\text{ATC}_1}{\text{Cwt. powder}} \quad (5)$$

Input cost per unit of powder is functionally related to the input cost per unit of skim by the same "K" input-output term defined above. Relationship (5) can therefore be restated as follows:

$$\frac{\text{Output price}}{\text{Cwt. powder}} \geq (K) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + \frac{\text{ATC}_1}{\text{Cwt. powder}} \quad (6)$$

where:

$$\frac{\text{Input cost}}{\text{Cwt. powder}} = (K) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) ,$$

K = functional relationship between physical quantities of skim input and powder output (approximately 11.2:1),  
and

ATC<sub>i</sub> = average total processing cost per cwt. powder at the i<sup>th</sup> level of annual production (Z).

Net profitability.--Total net profitability of model plant operations will be the amount by which total revenue exceeds total costs in notation (3):

$$\text{Net profit} = (Z) \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) - \left[ (K) (Z) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + \text{TC}_i \right] \quad (7)$$

The average net profit per unit of product can be stated from notation (5) as the difference between average total revenue and average total cost:

$$\frac{\text{Net profit}}{\text{Cwt. powder}} = \frac{\text{Output price}}{\text{Cwt. powder}} - \left[ \frac{\text{Input cost}}{\text{Cwt. powder}} + \frac{\text{ATC}_1}{\text{Cwt. powder}} \right] \quad (8)$$

Break-even volume of annual production.--It may be advantageous to be able to calculate the break-even volume of annual production for the model plant under some given set of prices for inputs and outputs. At the break-even volume of annual production total costs and total revenues will be equal and net profit will be zero. Notation (7) can therefore be used for calculation of the break-even volume of production in the following manner:

$$\text{Net profit} = Z \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) - \left[ (K) (Z) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + TC_i \right] \quad (7)$$

where (at the break-even point):

$$\text{Net profit} = \text{Zero} \quad (9)$$

then:

$$\text{Zero} = Z \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) - \left[ (K) (Z) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + TC_i \right] \quad (10)$$

$$Z = \frac{(K) (Z) (\text{Input cost/cwt. skim}) + TC_i}{\text{Output price/cwt. powder}} \quad (11)$$

Similarly, average net profit per unit of product will also be zero at the break-even volume of production:

$$\text{Zero} = \frac{\text{Output price}}{\text{Cwt. powder}} - \left[ K \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + \left( \frac{ATC_i}{\text{Cwt. powder}} \right) \right] \quad (12)$$

$$= \frac{\text{Output price}}{\text{Cwt. powder}} - \left[ K \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + \left( \frac{a + c_i X}{Z} + d_i \right) \right] \quad (13)$$

$$Z = \frac{a + c_i X}{\frac{\text{Output price}}{\text{Cwt. powder}} - K \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) - d_i} \quad (14)$$

Break-even price/cost relationship.--Previous relationships can be utilized to develop a notation that would be useful in stating the relationship between skim milk input and powder output prices which would



be associated with break-even conditions at any given level of annual production (Z). Reference to notation (10) is made for the total cost notation basis for this step:

$$\text{Zero} = Z \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) - \left[ (K) (Z) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + TC_1 \right] \quad (10)$$

where:

$$(K) (Z) \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) = \text{Total input cost} \quad (15)$$

then:

$$Z \left( \frac{\text{Output price}}{\text{Cwt. powder}} \right) = \text{Total input cost} + TC_1 \quad (16)$$

Notation (16) can be further modified by division of each side by total annual production (Z):

$$\frac{\text{Output price}}{\text{Cwt. powder}} = \frac{\text{Input cost}}{\text{Cwt. powder}} + \frac{ATC_1}{\text{Cwt. powder}} \quad (17)$$

$$\frac{\text{Output price/cwt. powder}}{\frac{\text{Input cost}}{\text{Cwt. powder}} + \frac{ATC_1}{\text{Cwt. powder}}} = 1 \quad (18)$$

Notation (18) indicates the relationship that will exist between price of the input and the output as compared to the average total cost ( $ATC_1$ ) associated with the selected annual production (Z) at a break-even condition.

Reference to notation (12) indicates the technique for development of the same relationship from average cost notations:

$$\text{Zero} = \frac{\text{Output price}}{\text{Cwt. powder}} - \left[ K \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) + \frac{ATC_1}{\text{Cwt. powder}} \right] \quad (12)$$

where:

$$K \left( \frac{\text{Input cost}}{\text{Cwt. skim}} \right) = \frac{\text{Input cost}}{\text{Cwt. powder}}$$

then:

$$\frac{\text{Output price/cwt. powder}}{\frac{\text{Input cost}}{\text{Cwt. powder}} + \frac{\text{ATC}_i}{\text{Cwt. powder}}} = 1 \quad (19)$$

Comparison of notations (18) and (19) indicates the algebraic equivalence of the total cost and average total cost approaches to the analysis of this section. No further application of these notations will be made in this study.<sup>1</sup>

#### Comparison of low-volume and high-volume milk drying plant processing costs

This study has concentrated upon the processing costs for a drying plant of relatively large size. Findings of this study could be used for comparison with processing costs of a smaller volume plant. Such a potential comparison might be useful either for evaluation of an investment decision for an existing plant, or it might be useful in an analysis of a potential merger of existing supplies for processing by a single high-volume plant utilizing technology outlined in this study.

A set of questions can be framed for the analysis to be presented in this section. Answers to these questions would provide information necessary for part of the analysis of a potential investment decision. Questions that embody the three essential investment decision factors could be as follows:

1. Does the initial investment that would be required for a high-volume plant exceed the initial investment that would be required for a low-volume plant (or for multiple installations of the low-volume plants)?

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<sup>1</sup>These relationships can be further adapted to express the effects of income taxes levied against the foregoing "profit" terms.

2. Is the average processing cost for a high-volume plant less than the average processing cost for a low-volume plant (or low-volume plant combinations) at the relevant production level?
3. Can a higher initial investment of a high-volume plant be recouped through lower processing costs within a reasonable period of time?

It will be noticed that each question presupposes an affirmative answer in the preceding question or questions. The analysis of this section will be directed at an answer for the third question. Such a question is relevant only if the preceding questions can be assumed to have been answered in the affirmative.

Results of any comparison between costs developed by this study and those of another study will be materially affected by the relative similarities and differences in basic assumptions. Ideally comparison would be made only for two studies based upon identical assumptions. Such coincidence, however, would be extraordinary unless one study was specifically designed for comparison with another. Otherwise, certain allowances must be made for variations of the two studies in order for comparison to be relevant.

Comparison of basic assumptions.--A study of processing costs in low-volume milk plants by Kolmer and Homme was selected for the comparison to be made in this section.<sup>1</sup> Basic assumptions are quite similar to those of the present study and the differences would not seem to be of major importance. Comparison of processing costs developed by the two

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<sup>1</sup>Lee Kolmer and Henry A. Homme, Spray Drying Costs in Low-volume Milk Plants (Ames, Iowa: Iowa State College, n.d.).



studies will be initiated in this section by a description of the Kolmer and Homme study.

The Kolmer and Homme study used the engineering method of cost determination exclusively.<sup>1</sup> This type of cost determination was also defined for use in the present study wherever adequate information based upon observation or from records of the case study plant could not be obtained. The present study did attempt to incorporate case study plant operating practices to the greatest extent practical.

Each of the two studies has regarded the milk drying process to be one directly associated with a multi-product dairy manufacturing plant. This has led to exclusion of costs for fluid milk procurement and costs for receiving and separation of whole milk in grade A operations of the plants. Both studies commenced cost calculations with the physical input requirements of the evaporator. Both sets of calculations were carried through to the point at which powder containers were loaded into place upon the means of transportation at the plant loading site.

The two studies were further alike in that neither allocated cost of land to the drying plant. Both studies, however, did allocate certain fixed costs of management, administrative and clerical services, insurance, taxes, interest on investment, and a charge for services of a plant foreman.

There were also several variations in assumptions of the two studies. The Kolmer and Homme study used a basic seven-day work week definition for its calculations while the present study was based upon either five-day or six-day definitions.<sup>2</sup> The processing costs associated

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<sup>1</sup>Ibid., 6.

<sup>2</sup>Ibid., 8.

with the six-day definition for the model plant will be used for the comparison in this section since it would seem to be more comparable to the Kolmer and Homme study.

The Kolmer and Homme study also used a forty-hour work week definition for the calculation of labor costs. It was assumed that labor would only be available in forty-hour per week increments and that any time required beyond the forty hours weekly would be paid time and a half.<sup>1</sup> The present study, however, adopted the assumption that the drying process would be part of a multi-product dairy manufacturing plant and variations in labor could be assimilated into the overall work pattern of the plant where such variations were within reason. This variation in the assumptions of the two studies will cause the labor costs of the present study to be somewhat less for otherwise similar ranges of production due to the greater flexibility of labor utilization.

Another variation between the two studies came in the charges that were made for storage of powder prior to sale. The Kolmer and Homme study assumed that powder would be in storage an average of two months prior to sale. They then assumed that a bank loan equal in value to an average two months' production would be required throughout the year. A \$0.15 per pound value was assigned to the powder and interest was figured at three and one-half percent per annum.<sup>2</sup> The present study assumed that powder in a high-volume plant would be moved out of storage again in relatively short periods of one or two weeks and no interest charges were made for powder in storage.

An additional difference is noted in the charges that were made for disposal of sewage. The Kolmer and Homme study allocated a fixed

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<sup>1</sup>Ibid.

<sup>2</sup>Ibid., 94.



charge for the costs of sewage disposal.<sup>1</sup> For present study it was observed that disposal charges for sewage varied to a considerable degree among different plants and often seemed to be affected by attitudes of the local governments. Disposal costs did not seem to be a major source of expense for those plants located outside of city limits. Therefore, due to the wide range of possibilities it was decided to exclude costs of sewage disposal from the study.

Components and processing costs of the low-volume plant.--The Kolmer and Homme study selected plant components to be used as a single unit with closely related capacity limitations for individual items of equipment. Criteria cited for equipment selection were as follows:

1. Sanitation and quality requirements,
2. Operating efficiency,
3. Space requirements,
4. Operating cost,
5. Initial cost, and
6. Future expansion.<sup>2</sup>

The combination of equipment selected for model plant III in that study is presented in Table 35.

The combination of equipment selected was considered to be the optimum combination for alternatives considered in the range of from 18,756 to 31,747 hundredweight of annual powder production. The equipment and labor organizations were optimums that were arrived at by a series of trial budgets and were based upon assumed seasonal production

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<sup>1</sup>Ibid., 87. The exact criteria for the charge could not be ascertained from the presentation, however.

<sup>2</sup>Ibid., 12.



fluctuations and peak requirements.<sup>1</sup> It might be noted that valuations of equipment, and therefore resulting processing costs, should be updated for increases in costs since the publication of the original study. Such an adjustment was not attempted in this study.

TABLE 35.--Description of equipment selected for low-volume model plant III and valuations assigned by the Kolmer and Homme study of low-volume milk drying plants<sup>a</sup>

Type of equipment	Description	Valuation
General equipment:		
Dryer . . . . .	650# per hour, Buflovak	\$ 36,650.00
Evaporator . . . . .	No. 55 Henzey (two effect)	26,000.00
Pre-heater . . . . .	16 x 1.5 x 12 Henzey	4,500.00
Hi-concentrate pre-heater	No. 21 Buflovak	2,500.00
Hotwell . . . . .	4 x 4 Rogers	1,342.00
Milk pump . . . . .	Tri-clover	75.00
Scale . . . . .	250# portable, Toledo	550.00
Shaker . . . . .		100.00
Propane gas equipment . .		2,000.00
Total general equipment		\$ 73,717.00
Boiler equipment:		
Boiler and burner . . . .	217 HP. (installed)	\$ 19,400.00
Water softener . . . . .		4,500.00
Total boiler equipment		\$ 23,900.00
Storage equipment:		
Forklift truck . . . . .		\$ 2,850.00
Pallets . . . . .		3,125.00
Total storage equipment		\$ 5,975.00
Buildings:		
Dryer building . . . . .		\$ 30,000.00
Boiler building . . . . .		4,200.00
Total buildings		\$ 34,200.00
Total plant investment		\$137,800.00

<sup>a</sup>Ibid., 80.

<sup>1</sup>Ibid., 8.

Processing costs assigned to various cost elements by the Kolmer and Homme study are presented in Table 36, for three different levels of annual production. Included are the highest and the lowest levels for which that study presents costs for the 650 pounds per hour dryer combination of plant equipment.

TABLE 36.--Input cost element costs per hundredweight for three levels of annual production as presented by the Kolmer and Homme study of low-volume milk drying plants<sup>a</sup>

Cost elements	Annual production (cwt.)		
	18,746	26,795	31,747
Building . . . . .	\$0.16	\$0.11	\$0.11
Equipment . . . . .	0.69	0.48	0.41
Boiler . . . . .	0.24	0.17	0.14
Insurance . . . . .	0.09	0.06	0.06
Taxes . . . . .	0.09	0.06	0.06
Quality control equipment . . . . .	-- <sup>b</sup>	-- <sup>b</sup>	-- <sup>b</sup>
Clerical labor . . . . .	0.06	0.04	0.03
Plant labor . . . . .	0.72	0.54	0.48
Fuel . . . . .	1.11	1.11	1.11
Electricity . . . . .	0.22	0.22	0.22
Water and sewage . . . . .	0.18	0.18	0.18
Packaging . . . . .	1.36	1.36	1.36
Supplies . . . . .	0.21	0.15	0.13
Seeling cost . . . . .	0.80	0.80	0.79
Total	\$5.90	\$5.28	\$5.08

<sup>a</sup>Ibid., 47.

<sup>b</sup>Less than one cent per hundredweight of powder.

The 31,747 hundredweight of powder per year level of production is approximately one fourth of the Coulter spray dryer capacity under the assumptions for which costs are presented in this study. Comparison of

the two technologies in this section will be made for a total of five annual production levels. The first two levels will be the lowest and highest volume levels of Table 36. The remaining three levels will be for production equivalent to twice, three times, and four times the highest level of Table 36. The higher levels of production would be analogous to comparison of costs for a single Coulter installation with the costs of multiple low-volume drying plant installations.

Comparison of initial and processing costs.--Both major similarities and variations between the two studies have been pointed out and a basis established for comparison. An analysis can be indicated for the three investment decision factors that were originally presented in question form. This particular analysis will necessarily make two assumptions pertaining to the costs presented by the two studies.

1. Variations in the underlying assumptions of the two studies will not be a source of sufficient variation in processing costs that have been developed by each study to preclude comparison.
2. Potential economies of size that might develop in multiple installations of low-volume technology in a single location are not sufficient to materially affect comparison.

The following analysis will be imprecise to the extent that these two assumptions might prove to be unwarranted and such potential imprecisions are recognized.

Average processing costs for both the high-volume plant (6-day, 100-lb., truck processing) and for multiple installations of the low-volume plant are presented in Figure 8. Points on the graph for the low-volume plant indicate additive multiples of plant installations and of average costs for production levels beyond the capacity of a single plant.



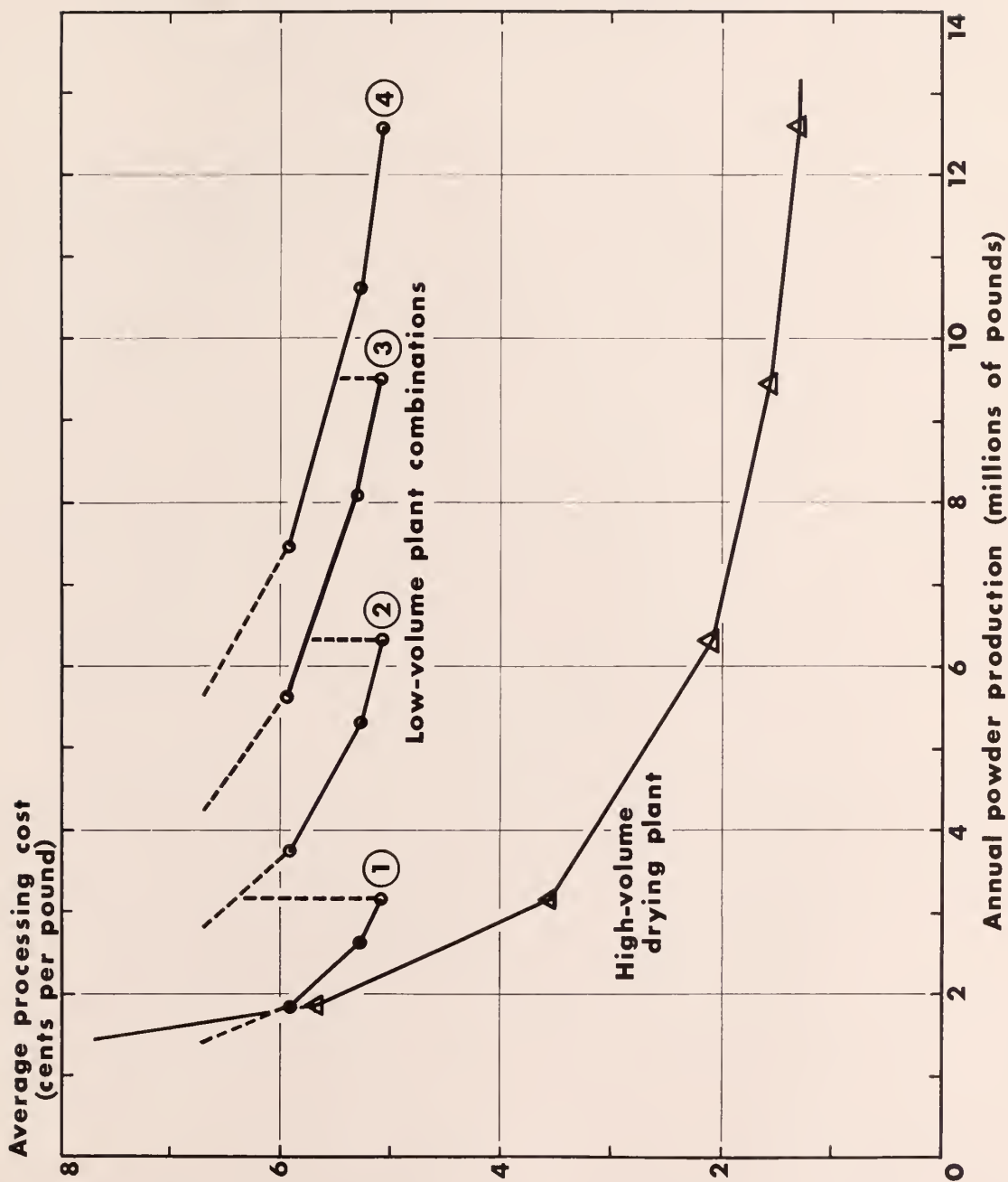


Fig. 8.--Comparison of average processing costs between a single installation of a high-volume drying plant and multiples of one, two, three, and four low-volume drying plants.

For production levels between the specific production levels selected for comparison in Table 37, average costs would lie above minimum average cost (\$5.08 per cwt.) due to underutilization of the multiple installations. Points selected for comparison in Table 37 therefore represent optimum utilizations of multiple low-volume plant combinations.

Table 37 presents a summary of the comparisons between the two types of plants at selected annual production levels. It contains initial acquisition costs and average processing costs and an analysis of the approximate relative production periods that would be necessary in order for potentially lower processing costs to offset higher initial costs of the high-volume plant.

The periods of time required to recoup differences in initial acquisition costs were obtained in the following manner. Given that processing costs of the high-volume plant are less than those for the low-volume plant, it is possible for the high-volume plant to recoup an initial acquisition cost disadvantage in some determinable period of time. This period of time (P) is a function of the difference in average processing costs (C) at relevant annual production levels, of total production (Q), and of the daily production rate (Y). This notion could be expressed in the form of the following notations:

$$Q_j = \frac{I_2 - I_1}{C_{1j} - C_{2j}} \quad (1)$$

where:

$Q_j$  = total powder production at the  $j^{\text{th}}$  annual production level required to recoup the difference in acquisition costs,

$I_1$  = initial investment for the low-volume plant,

$I_2$  = initial investment for the high-volume plant,

TABLE 37.--Acquisition costs, average processing costs, and periods of time necessary to recoup differences in acquisition costs when comparing low-volume to high-volume milk drying plants at selected annual powder production levels

Item	Annual powder production levels in cwt. (j)			
	18,756	31,747	63,594	95,241
Initial investment:				126,988
High-volume ( $I_{2j}$ ) . . . . .	\$438,174.00	\$438,174.00	\$438,174.00	\$ 438,174.00
Low-volume ( $I_{1j}$ ) . . . . .	137,800.00	137,800.00	275,600.00	551,200.00
( $I_{2j} - I_{1j}$ ) . . . . .	\$300,374.00	\$300,374.00	\$152,574.00	\$-133,026.00
Average processing cost:				
Low-volume ( $C_{1j}$ ) . . . . .	\$5.90	\$5.08	\$5.08	\$5.08
High-volume ( $C_{2j}$ ) <sup>a</sup> . . . . .	5.64	3.57	2.07	1.57
( $C_{1j} - C_{2j}$ ) . . . . .	\$0.26	\$1.51	\$3.01	\$3.51
Cwt. daily prod. ( $Y_j$ ) <sup>b</sup> . . . . .	61.29	103.75	207.82	311.24
Production to recoup:				406.35
Cwt. of powder ( $Q_j$ ) . . . . .	1,155,284.62	198,923.18	50,689.04	7,058.12
Processing days ( $P_j$ ) <sup>b</sup> . . . . .	18,848.25	1,917.36	243.90	22.68
Processing weeks <sup>b</sup> . . . . .	3,141.38	319.56	40.65	3.78
Processing months <sup>b</sup> . . . . .	785.34	79.89	10.16	0.94

<sup>a</sup>Costs for the high-volume plant are those associated with 6-day, 100-lb. plain, truck processing.

<sup>b</sup>Using the same definition as for Table 22: 1 yr. = 306 da.; 1 mo. = 4 da.; 1 wk. = 6 da.



$C_{1j}$  = average processing cost for the low-volume plant at the  $j^{\text{th}}$  annual production level, and

$C_{2j}$  = average processing cost for the high-volume plant at the  $j^{\text{th}}$  annual production level.

Equation (1) was relevant to this analysis only for conditions in which  $I_2 > I_1$ , and  $C_{1j} > C_{2j}$ . These two conditions were analogous to affirmative answers to questions one and two from the first of this section.

These conditions were met only for the first four annual production levels of Table 37. The highest level of production required a multiple of four individual low-volume plants with a total initial cost in excess of that for the high-volume plant ( $I_1 > I_2$ ).

The period of time (P) required for recovery of the initial cost disadvantage was obtained from notation (1) as follows:

$$P_j = \frac{Q_j}{Y_j} \quad (2)$$

where:

$P_j$  = time period required for recovery of the initial cost disadvantage at the  $j^{\text{th}}$  annual production level,

$Q_j$  = as defined in (1), and

$Y_j$  = daily production rate obtained by spreading the  $j^{\text{th}}$  annual production level equally over 306 processing days ( $Z/306$ ).<sup>1</sup>

The presentation of Table 37 can be restated in a set of general observations. At the lowest level of annual production considered the high-volume plant would be operating at only fourteen percent of its capacity and the low-volume plant would be operating at sixty percent.

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<sup>1</sup>See Table 22 in the Total cost section of Part V for "processing day" calculations.

Although average processing cost for the high-volume plant is slightly less than for the low-volume plant, it would require in excess of sixty-five years to recoup the \$300,374 difference in initial costs. The high-volume plant is not competitive at this greatly reduced annual production level.

The second annual production level represents one hundred percent capacity for the low-volume plant and about twenty-four percent capacity for the high-volume plant. Even though the low-volume plant has reached its maximum efficiency level of output, average processing cost has not declined as rapidly as it has for the high-volume plant. As a result, it would only require about six and one-half years to recoup the same \$300,374 difference in initial costs. Since life expectancy of drying equipment is in excess of six years, even with allowance for obsolescence, it would appear that the high-volume plant has become competitive with this very low-volume plant even within the production capacity range of the single low-volume plant installation.

Each of the three remaining levels of annual production involve duplication of the low-volume plant equipment. It has already been pointed out that each level presented is a multiple of the maximum efficiency level of production for a single low-volume plant. At production levels intermediate to those selected, average costs will lie above those shown in Table 37 due to under-utilization of the low-volume equipment. With recovery of the difference in initial costs in less than a year for both production levels associated with multiples of two or three low-volume plants, it is unlikely that any intermediate combination of low-volume plants could be competitive with the high-volume plant.

At the highest level of annual production, associated with an installation requiring four low-volume plants, initial cost of the



low-volume plants exceeds that of the high-volume plant. The high-volume plant is at an absolute advantage from the time of installation at this production level.

It would be possible to include an additional factor in the analysis of potential cost economies to be realized by manufacturers from a consolidation of milk supplies. This refinement of the analysis would be in recognition of the fact that a consolidation of milk supplies from several individual processing locations might result in either cost economies or diseconomies in the procurement and transportation functions depending upon various factors in a given situation.

If consolidation of milk supplies incurred diseconomies in the procurement and transportation functions, the processing cost advantage for the high-volume plant would be less and recovery of a greater high-volume plant initial cost would be correspondingly less rapid. Recovery would be more rapid, however, if consolidation resulted in cost economies in these functions. Analysis of this additional factor will be indicated in general notation form only. No attempt will be made in this study to apply this technique to the analysis of a specific situation.

The analytical notation previously presented for Table 37 can be expanded to include these costs of procurement and transportation. It will be assumed that costs of the two functions can be combined and stated as a single average cost per unit of skim milk input (or per unit of fluid whole milk with necessary calculation allowances). Application of an appropriate skim-to-powder physical conversion ratio will permit restatement of average combined cost on the basis of powder output units.

The required skim-to-powder ratios appropriate for each of the plants can be obtained in the following manner. It has been estimated



that 8.4 pounds of powder would be produced from each one hundred pounds of skim milk in the low-volume plant.<sup>1</sup> The reciprocal of this relationship is equivalent to a skim-to-powder ratio of 11.9:1, which indicates that it would require 11.9 pounds of skim milk to produce each pound of powder. The skim-to-powder ratio has also been calculated for the high-volume plant from case study plant records and is equal to 11.2 pounds of skim required per pound of powder.<sup>2</sup>

The general notation for this additional analysis can be stated with the use of these two skim-to-powder ratios. The combined cost of the two additional functions per hundredweight of powder can be calculated for each plant as follows:

$$C'_i = \left( \frac{\text{Avg. proc't \& transp. cost}}{\text{Cwt. skim milk}} \right) \left( \frac{\text{Lbs. skim}}{\text{Lb. powder}} \right) \quad (3)$$

where:

$C'_i$  = average procurement and transportation cost per cwt. powder for the  $i^{\text{th}}$  type of plant ( $i = 1$  for low-volume;  $i = 2$  for high-volume),

then:

$$C'_1 = \left( \frac{\text{Avg. proc't \& transp. cost}}{\text{Cwt. skim milk}} \right) (11.9) \quad , \text{ and} \quad (4)$$

$$C'_2 = \left( \frac{\text{Avg. proc't \& transp. cost}}{\text{Cwt. skim milk}} \right) (11.2) \quad . \quad (5)$$

The initial cost difference recovery production quantities ( $Q_j$ ) previously presented can also be adapted to include this additional cost source:

$$Q_j = \frac{I_2 - I_1}{(C_{1j} + C'_1) - (C_{2j} + C'_2)} \quad (6)$$

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<sup>1</sup>Ibid., 8.

<sup>2</sup>See Appendix E.

where:

$Q_j$  = total powder production at the  $j^{\text{th}}$  annual production level required to recoup the difference in acquisition costs,

$I_1$  = initial investment for the low-volume plant,

$I_2$  = initial investment for the high-volume plant,

$C_{1j}$  = average processing cost for the low-volume plant at the  $j^{\text{th}}$  annual production level,

$C_{2j}$  = average processing cost for the high-volume plant at the  $j^{\text{th}}$  annual production level,

$C'_1$  = average procurement and transportation cost per cwt. powder for the low-volume plant, and

$C'_2$  = average procurement and transportation cost per cwt. powder for the high-volume plant.

These " $Q_j$ " values are then used for calculation of the time period ( $P_j$ ) required for the recovery of the initial investment difference in the same manner as stated in notation (2) of this section.

Analysis of the resulting " $P_j$ " time periods would proceed in the same manner as performed for Table 37. One additional general observation is applicable, however. The skim-to-powder ratio for the low-volume plant is approximately six percent larger than for the high-volume plant. Subject to the accuracy of these two values, consolidation of milk supplies could result in a six percent increase in the costs of the procurement and transportation without causing the comparison of the two types of plants to become any less favorable for the high-volume drying plant than for the analysis of Table 37.

Given the degree of accuracy for the various assumptions upon which the analysis has been based, it would appear that the high-volume plant is associated with sufficient cost economies so that a potential consolidation of fluid milk market supplies for drying in a central installation would bear further analysis. It is recognized, however, that final analysis of the alternatives outlined may well embrace noneconomic factors not subject to the type of analysis presented here.



## VI. LIMITATIONS AND SUGGESTIONS FOR FUTURE STUDY

### Limitations of the Study

Several considerations limiting the representativeness and applicability of the study findings can be pointed out. These limiting considerations can be roughly characterized as those which have been explicitly indicated in the course of the study as "simplifying technological assumptions," and secondly, those that are implicit in the technique used in the study.

#### Limitations explicitly imposed by simplifying technological assumptions

A number of simplifying technological assumptions were stated for the study at the close of Part III. The limitations imposed by each of these simplifications can be examined in much the same sequence.

#### General setting of the milk drying process

The milk drying process has been assumed to be associated with a multi-product dairy manufacturing plant. This assumption was the basis for specification of processing techniques for the model plant and for allocation of various fixed costs. The following limitations attributable to this assumption can be noted.

Procurement, receiving, and cream separating functions.--No costs were allocated to the dry milk product for these processing functions. The full processing cost of dry milk should, however, include an allocation of a portion of these costs from the grade A milk department to the

dry milk product. It would be necessary for a drying plant not operating in association with a multi-product dairy manufacturing plant either to provide these functions or to pay for them in the delivered raw milk input.

Availability of labor.--Labor was assumed to be freely available at the wage rate specified. There were no overtime charges or minimum wage restrictions for key labor personnel. It was assumed that temporary fluctuations in labor requirements could be assimilated into the labor requirements of the associated multi-product plant.

This assumption is strictly justifiable only within approximately the range of operations experienced by the case study plant. Extension of this assumption to all possible ranges of production of the model plant has probably resulted in an under-statement of processing costs at both the high and low extremes of processing. A model plant operating over extended ranges of production would undoubtedly encounter the necessity for retention of key personnel and for payment of overtime.

Allocation of fixed costs.--Fixed costs for the multi-product manufacturing plant were allocated to the dry milk process by means of several arbitrary criteria. It is recognized that there is no precisely defensible criteria for allocation of joint costs within an individual production unit. The approximate allocations made in this study represent an attempt to indicate the general magnitude of such fixed expenses as might reasonably be expected to be encountered by a model plant operating independently of a multi-product plant.

It has previously been pointed out that some of the costs that were allocated in this study were not actually joint costs. Modification of accounting methods could possibly provide for direct allocation of costs to individual equipment items. Maintenance labor and supplies would



be examples of these types of costs. The actual fixed expenses that would be experienced by a model plant installation could possibly be affected both by its association with a multi-product plant, and by the size of the plant if it was so associated.

#### Final products of the model plant

Processing cost variations considered by this study were limited to those associated with preventive maintenance expenditures in the drying stage, dry milk container requirements in the bagging stage, and load-out requirements in the powder loading stages. It is quite likely that there were other cost element requirement variations that were eliminated from consideration by use of engineering approaches to cost element requirement measurements. It is probable, however, that these potential variations are not critically large and would not therefore appreciably alter the cost relationships.

#### Processing rate and interconnection of equipment

Model plant production has been assumed to be limited by the output of the evaporator. The evaporator was the limiting equipment both for the processing rate during the production run and for the length of production run. The production limitation of the model plant could be changed considerably by very minor alterations.

It has been assumed that all condensed product produced by the evaporator would be processed by the dryer and that the dryer would be limited to the output of the evaporator. Production of the model plant could be increased in two ways by relaxation of this assumption in order to permit outside purchases of condensed product and its temporary storage. The dryer would thereby be able to continue processing for a longer period during the twenty-four hour production run even though the evaporating



stage had been shut down for its cleanup phase. Secondly, the quantity of condensed product in temporary storage could be used to supplement the output of the evaporator in order to more completely utilize the processing rate capacity of the dryer.

These adaptations of the model plant would appear to offer opportunities for lower operating costs through greater output and lower average fixed costs. It is probable, however, that they would also entail higher variable costs and the net effect is not known.

#### Fixed cleanup phase duration

The cleanup phase, when occurring in a stage, has been assumed to be of a single, fixed duration for all volumes of production. This assumption is strictly defensible only within the approximate range of case study plant production. It is quite possible that cleaning requirements could be appreciably reduced at extremely low volumes of daily production. It is also possible that cleaning requirements might have to be supplemented as the maximum daily production limitation is approached. This limitation possibly results in an overstatement of processing costs at low levels of production, and a corresponding understatement at high levels of production.

#### Variable phase linearity

The length of each of the variable phases has been assumed to be directly proportional to the quantity of product processed. This assumption would appear to be reasonably justified for the "processing" phases of each stage. The individual items of equipment have been designed to operate at a fixed rate of processing and all plant equipment operates at a rate determined by the equipment having the lowest capacity.

Justification of this assumption is far more difficult, however,

for the "maintenance" phases of the drying and bagging stages. Downtime data was limited for the case study plant and statistical analysis was inconclusive. It is quite possible that there are factors affecting downtime in these two stages other than volume of production. No concrete indication can be given as to the possible net effects of these other potential variables or even as to their identity.

#### Implicit limitations

There are also a number of limitations implicit in the techniques employed for this study which have not been stated elsewhere as explicit assumptions. These factors are none-the-less important considerations in an overall evaluation of the study findings.

#### Level of management and degree of operating efficiency

Comparisons of costs and profits can be made for similar types of businesses as a measure of the level of management and degree of operating efficiency. It would therefore follow that a description of costs for a particular business is relevant only for the particular management and supervisory services being performed. The relationship is recognized but no measure of these services was attempted.

#### Variations in cost element requirements

Utility cost element requirements were calculated by reference to engineering specifications of the equipment and appropriate estimating functions. This method probably produces results that are generally applicable. They do not, however, provide for cost element requirement variations due to individual installation conditions, individual operating techniques or other external variables such as outside air temperatures or relative humidities.



### Availability of natural gas

Cost element requirements were calculated for operations with natural gas being used in the steam boilers and the dryer burners. These requirements and the resulting costs are inapplicable if natural gas is not available.

### Accounting procedures

This study has used a straight-line depreciation schedule with no salvage value allowed at the end of the useful life. Interest and taxes were calculated on an "average" investment. These methods give representative costs when considering the entire life of the model plant.

Plant management may, in fact, wish to consider certain of these costs at higher levels during the first years of useful life. The basic property valuations established in this study could be adapted to a "declining balance" or "sum of the years-digits" method of depreciation accounting. Plant expenses for interest, taxes, and insurance could also be budgeted on an annual basis with appropriate annual allowances throughout model plant life. These adaptations of fixed cost calculations would cause average costs to be higher than calculated in this study during the first half of the plant life. They would subsequently be lower during the last half and would have declined annually throughout.

As a contrasting consideration, there would be certain expenses which would tend to increase during life of the plant. Expenses such as maintenance of the building and repairs to the equipment would probably show this tendency. Budgeting of these expenses would tend to increase average cost throughout the useful life of the plant.

Finally, there are certain tax relief measures and investment incentives which would be pertinent to management decision-making. In



general these adjustments will tend to decrease cost in the early part of the investment period when observed in cost calculations.

#### Factor prices

Costs presented in Part V are based upon the single set of input factor prices detailed in Appendix I. These prices would appear to be reasonable for a multi-product dairy plant in the mid-west but there are considerations which would cause these prices to be considered inappropriate.

The size of dairy plant with which the model plant was associated would affect the utility rates for electricity, natural gas, and water. Most utility rates are constructed to provide for declining unit charges as monthly volume increases. A model plant associated with a large dairy plant would therefore probably benefit from lower utility rates than would a model plant operated independently of a multi-product plant.

Similar considerations would apply to purchase of supply items which could also be used in other areas of multi-product plant. Purchase in bulk lots could possibly result in discount allowances by the supplier.

There would be offsetting tendencies active for labor and wage considerations. A model plant installed independently would not have a labor supply as flexible as assumed for this study. Minimum wages (forty hour per week labor increments) and overtime charges would be a greater consideration. On the other hand, however, the labor force is likely to be more highly organized in a large plant. There will probably be more pressure for restrictive union agreements and fringe benefits than would be encountered with a small labor force.

To the extent that factor markets are imperfectly competitive there will be considerations present which will tend to create variations in

prices charged to individual buyers. No complete description of all such possibilities can be offered.

### Suggestions for Future Study

Many possibilities for extending the analysis presented in this study suggest themselves. The suggestions that will be presented can be classified into those which entail refinement of the cost element requirements established by this study, and those suggestions which would extend the analysis to include other factors of interest. Many of these considerations have been pointed out throughout the study and more specifically in the preceding "limitations" section.

#### Refinement of cost element requirements

The cost element requirements could be further studied by additional analysis designed to either verify the engineering estimating functions or to provide additional data.

#### Engineering estimating functions

Engineering estimating functions were used extensively for calculation of electrical requirements of motors, steam requirements for the evaporator, and for calculation of a steam cost of production. These requirements could be verified by installation of various types of measuring and recording equipment.

In particular, the actual electrical requirements of motors installed in a plant, overall steam requirement, and steam distribution system efficiency would be of interest. Additional data would also be able to provide more information on the gas requirements of the dryer and would verify the gas requirement calculations for the steam boiler.

These measurements could also be designed to measure and record variations caused by changes in atmospheric conditions and operator technique.

#### Solids losses

Solids losses were calculated by a recapitulation of milk solids processed by the case study plant over a period of time. The possible locations of potential solids losses were described in Appendix E and illustrated in Figure 10. It was not possible, however, to establish the relative importance of the various potential solids losses.

Present operation already provides for measurement of the flow of skim to the evaporator with a flow meter, weights of condensed product purchased and sold as well as the weight of dry powder. Installation of flow meters to measure and record quantities of condensed product leaving the evaporator and quantities of condensed product entering the dryer would provide the additional information necessary.

#### Dryer downtime

Incidence of dryer downtime appeared to be sufficient to possibly warrant additional measurement and statistical analysis. Additional data might be gathered by means of techniques such as ratio-delay studies or automatic measuring and recording devices.

#### Labor restrictions

Modifications could be made in order to approximate various degrees of labor input factor lumpiness. This would involve both minimum wage and overtime specifications. Greater attention could also be given to additional costs such as withholding and compensation taxes, sick leave, retirement or pension programs, and other fringe benefits.



### Accounting procedures

As indicated in the "limitations" section, it is often useful to business management to have costs expressed in terms other than the average useful lifetime costs as calculated in this study. This modification could be easily handled by budgeting the fixed annual costs. Depreciation could be figured on either the "declining balance" or the "sum of the years-digits" methods. Interest expenses, property and other taxes, insurance premiums and maintenance expenses could likewise be budgeted to reflect specific conditions and special considerations.

### Costs analysis by stages and phases

The mathematical model summation notations could be adjusted to provide for aggregation and calculation of costs by various stages and/or phases. Cost analysis could then be made between stages or between phases in addition to the comparison between cost elements presented in Part V.

### Programmed cost aggregation and calculation

The mathematical model developed for this study could be used as a framework for writing a cost calculation computer program. This would provide a quick and efficient method for aggregating and calculating cost element costs for future cost studies. Attention could thereby be concentrated upon the techniques for measuring and recording various cost element requirements. Subsequent aggregation and calculation procedures would be handled mechanically.

### Extension of analysis

Analysis of the costs for drying milk could be extended in at least four ways. Analysis could be extended back in sequence to previous

functions, it could be adapted for analysis of a "skim-storage" or a "condensed-storage" model, or it could be extended to varying types and volumes of drying technology.

#### Additional processing functions

The full processing cost of dry milk must involve an allocation of costs incurred by the dairy plant for the procurement, transportation, milk receiving, and cream separating functions. Analysis similar to that employed in this study could be applied to these areas. A model drying plant operating independently of a multi-product dairy plant would either be required to provide for these services or would pay for them in the cost of the skim milk input.

#### Skim storage model

It is probable that there would be a daily volume of production so small that it would be profitable for the model plant to store that quantity of skim milk overnight. It would be necessary to analyze the skim milk refrigerated storage costs and to compare them to the fixed production run costs for preparation and cleanup of equipment. This would provide a maximum daily volume limit for which it would be profitable to store skim milk for processing on the following day.

#### Condensed product storage model

It has been pointed out that the production of the dryer is limited both by the lower processing rate and by the longer cleanup requirement of the evaporator. These limitations could be avoided for the combination of dryer and evaporator analyzed in this study by purchase and storage of condensed product.

In order to be able to completely analyze this operating alternative it would be necessary to make two additional cost analyses. Operation of the drying and bagging stages separately from the evaporating stage would require analysis of costs by stages as suggested above. In addition, it would also be necessary to state average costs for the higher hourly processing rate that would be used.

#### Analysis of additional technologies

It was observed in Part V that comparison of costs ideally is made only for processing combinations studied by the same techniques and using the same set of assumptions. Application of the analytical technique used in this study to various technological combinations would provide an indication of the long-run production possibility curve for milk drying technology.



## VII. SUMMARY AND CONCLUSIONS

Two basic hypotheses were initially stated for this study. It was hypothesized that acquisition costs of high-volume drying equipment did not create an effective barrier to use of new high-volume drying technology. It was further hypothesized that any initial cost disadvantage could be recovered in a reasonable period of time through lower processing costs. Specific criteria were not defined for either "effective barriers" or "reasonable periods," however. Analytical conclusions can therefore be made in general terms only.

The initial acquisition cost calculated for the high-volume drying plant in Part IV was \$438,174.00. "Effectiveness" of this initial acquisition cost as a barrier to adoption of the new technology will depend to a large extent upon the financial condition of the individual organization. Whereas it would not seem to be a prohibitive investment for an established plant of medium to large size, it might not be feasible for a small plant without an established credit reputation or adequate financing.

The periods of time required to recover additional acquisition costs when compared to a low-volume drying plant were analyzed for one particular low-volume technology in Part V. Selection of the low-volume plant for the comparison was made on the basis of similarities between the study in which it had been described and the present study.

Comparative analysis in Part V provided estimates of the initial acquisition cost difference recovery periods at various levels of annual production. The recovery period at an annual production of

1,875,600 pounds of powder was calculated to be over sixty-five years. It is obvious that this would not likely be considered to be a "reasonable" period of time for cost recovery.

The recovery period at an annual production of 3,174,700 pounds was estimated to be approximately six and a half years. This production level represents maximum production for the low-volume plant and therefore minimum average cost. Whether this recovery period would seem to be "reasonable" to plant management would probably depend upon individual business considerations. It well may be that conditions similar to those that could possibly tend to make the initial acquisition cost appear to be a barrier, would also tend to make this recovery period appear unreasonable.

Average costs for any multiple of low-volume plants were demonstrated to be equal to or greater than minimum average cost for a single plant. An annual production of 6,359,400 pounds represented maximum production for a combination of two low-volume plants. The recovery period at this annual volume was estimated to be only ten months. This would appear to be a fully "reasonable" recovery period. Recovery period at maximum production for three volume plants was less than a month. The initial acquisition costs for a combination of four plants exceeded the initial cost for the high-volume plant.

It can therefore be concluded that the period of time necessary to effect recovery of a high-volume plant initial acquisition cost disadvantage, as compared with multiple low-volume installations, decreases as annual production is increased. It would also appear that the recovery period would be short enough to be considered "reasonable" for the comparison of any multiple low-volume installation with the high-volume plant.



In addition to these major conclusions required for the hypotheses stated for this study, certain other general conclusions can be made pertaining to operations of the case study plant. It was estimated that maximum annual powder production would be approximately 10,981,200 pounds for the five-day week definition, or 13,229,400 pounds for the six-day week definition. The two-year average level of production was determined from case study plant records to be about 6,992,000 pounds. This represents roughly sixty-four percent of maximum production for five-day weeks or fifty-three percent for six-day weeks.

Average processing costs for the model plant ran from a high of about \$10.22 per hundredweight at an annual production of 10,000 hundredweight, to a low of about \$1.40 per hundredweight at 132,294 hundredweight annually. Costs had declined to a range of \$1.91 to \$2.04 per hundredweight for different types of processing at the two-year average annual production level for the case study plant. A model plant operating at the two-year average annual production level of the case study plant could decrease average processing costs by an estimated \$0.49 per hundredweight for five-day week processing by increasing annual production to the maximum capacity limitations. The decrease in average cost for six-day weeks was similarly estimated to be about \$0.64 per hundredweight.

It can therefore be concluded that the case study plant was operating at somewhere between one half and two thirds of maximum capacity during the period of this study. It can also be concluded that average processing costs could probably be lowered by an estimated twenty-five or thirty-two percent respectively for the five and six-day weeks by increasing output to the maximum estimated capacity limitation.



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## APPENDIX A

## Inventory of Model Plant Equipment

Table 38 of this section provides an inventory of the equipment pertinent to the "milk drying process" as defined in this study. Not all equipment that will be discussed in Appendix B is included in this inventory. Some of the equipment considered necessary to an explanation of the product flow in the plant studied (i.e., cream separators, etc.) was not subsequently considered to be within the limits of the cost study as defined. The inventory does not cover such areas as office equipment, laboratory equipment, or equipment associated with the manufacture of steam.

Key numbers are the same as used in Appendix B and in references throughout the study.

TABLE 38.—Inventory of equipment for the model plant evaporating, drying, bagging, storage, and load-out stages

Equipment	Rating, size or capacity	Key
Evaporator equipment:		
Evaporator milk supply motor and pump . .	5 HP.	9
Evaporator flow meter . . . . .		10
2nd-effect interstage heater . . . . .		11
1st-effect interstage heater . . . . .		12
Live steam heater motor and pump . . . .	10 HP.	13
Live steam heater . . . . .	40,000 lbs./hr. from 145°F. to 200°F.	14



TABLE 38.--Continued

Equipment	Rating, size or capacity	Key
Hot well . . . . .	850 gallons	15
Hot-well motor and pump . . . . .	3 HP.	16
Grade A surge tank . . . . .	50 gallons	17
Holding tube motor and pump . . . . .	7.5 HP.	18
Holding tube . . . . .	16 seconds at 40,000 lbs./hr.	19
Flow-diversion valve . . . . .		20
Thermo-compressor . . . . .	8,361.1 lbs. steam per hour	21
1st-effect liquid level valve . . . . .		22
1st-effect chest . . . . .		23
1st-effect chest condensate motor and pump	1.5 HP.	24
Condensate reservoir . . . . .	Approx. 100 gals.	25
Turbidity detector and valve . . . . .		26
1st-effect separator . . . . .		27
2nd-effect liquid level valve . . . . .		28
2nd-effect chest . . . . .		29
2nd-effect chest and 1st-effect interstage heater condensate motor and pump . . . . .	1 HP.	30
2nd-effect separator . . . . .		31
3rd-effect liquid level valve . . . . .		32
3rd-effect chest . . . . .		33
3rd-effect chest and 2nd-effect interstage heater condensate motor and pump . . . . .	1 HP.	34
3rd-effect separator . . . . .		35
3rd-effect vapor heater no. 1 . . . . .		36
3rd-effect vapor heater no. 2 . . . . .		37

TABLE 38.—Continued

Equipment	Rating, size or capacity	Key
3rd-effect vapor heaters condensate motor and pump . . . . .	1 HP.	38
Intermediate steam jet air ejector . . .		39
Counter-current condensor . . . . .	425 gallons of water per min.	40
Steam jet air ejector (hogging jet) . . .	204.4 lbs. steam per hour	41
Condensor motor and pump . . . . .	40 HP.	42
Cooling tower no. 1 (large) . . . . .	305 GPM. from 115° to 88° at 78° wet bulb	43
Cooling tower no. 1 fan and motor . . . .	10 HP.	44
Cooling tower no. 2 . . . . .		45
Cooling tower no. 2 fan and motor . . . .	5 HP.	46
Product removal pump and motor . . . . .	3 HP. variable speed pump	47
CIP motor and pump no. 1 . . . . .	10 HP.	102
CIP motor and pump no. 2 . . . . .	5 HP.	103
Evaporator control center . . . . .		88
Dryer equipment:		
Portable transfer pump and dryer cleanup pump and motor . . . . .	10 HP.	50
High-pressure dryer feed pump and motor .	50 HP.	51
Drying chamber . . . . .		52
Air intake filter . . . . .		53
Air intake fan and motor . . . . .	75 HP.	54
Gas burner fan and motor . . . . .	20 HP.	55

TABLE 38.--Continued

Equipment	Rating, size or capacity	Key
Gas-air jets . . . . .		56
Gas burner . . . . .		57
Powder-air separator no. 1 . . . . .		58
Powder-air separator no. 2 . . . . .		59
Airlock and motor no. 1 . . . . .	0.25 HP.	60
Airlock and motor no. 2 . . . . .	0.25 HP.	61
Powder redrier no. 1 . . . . .		62
Powder redrier no. 2 . . . . .	0.25 HP.	63
Redrier air intake filter . . . . .		64
Redrier air heater . . . . .		65
Powder collector no. 1 . . . . .		66
Airlock and motor no. 3 . . . . .	0.25 HP.	67
Powder redrier no. 3 . . . . .		68
Powder collector no. 2 . . . . .		69
Airlock and motor no. 4 . . . . .	0.25 HP.	70
Powder redrier no. 4 . . . . .		71
Powder collector no. 3 . . . . .		72
Airlock and motor no. 5 . . . . .	0.25 HP.	73
Powder cooler no. 1 . . . . .		74
Powder cooler no. 1 air filter . . . . .		75
Powder collector no. 4 . . . . .		76
Airlock and motor no. 6 . . . . .	0.25 HP.	77
Powder cooler no. 2 . . . . .		78
Powder cooler no. 2 air filter . . . . .		79



TABLE 38.--Continued

Equipment	Rating, size or capacity	Key
Powder collector no. 5 . . . . .		80
Airlock and motor no. 7 . . . . .	0.25 HP.	81
Cyclocentric powder sifter and motor . .	5 HP.	82
Transfer fan and motor . . . . .	25 HP.	83
Exhaust fan and motor . . . . .	100 HP.	84
Dryer control center . . . . .		85
Reservoir for dryer cleanup . . . . .	150 gallons	86
Manual loader for renewing air filters .		87
Miscellaneous equipment:		
Cooling plate . . . . .		48
Condensed milk insulated storage vat . .	5,000 gallon	49
Portable fan . . . . .	0.25 HP.	89
Roof fan no. 1 . . . . .	0.5 HP.	90
Roof fan no. 2 . . . . .	0.25 HP.	91
Roof fan no. 3 . . . . .	0.25 HP.	92
Platform scales . . . . .	250 lb. cap., dial reading in quarter pounds	93
Sewing machine . . . . .	0.25 HP.	94
Moisture tester . . . . .	250 watt bulb	95
Stencil cutter . . . . .		96
Stencil brush . . . . .		97
Electric forklift . . . . .	48 in. load length, 121 in. lift, 2,000 pound capacity	98

TABLE 38.--Continued

Equipment	Rating, size or capacity	Key
Battery recharger . . . . .	For 24 volt, fork- lift batteries	99
Magnesium forklift ramp . . . . .		100
Wooden storage pallets . . . . .	600; 3 ft. x 4 ft. 6 in.	101

## APPENDIX B

## Processing Product Flow Description by Stages

A detailed description of the product flow in the model plant will be presented in this section. Definitions for processing stages introduced in Part III are used to subdivide the product flow for presentation of the description. Reference can be made to Figure 9 at the end of this appendix for an illustration of product flow in the evaporating, drying, and bagging stages.

Stage I: Evaporating

Product flow.---This stage included all activities from the time that skim milk left the storage vat until condensed product had either been cooled and placed in the storage vat or until warm condensed product entered the drying stage.

Processing began with skim milk in the storage vat (8) at a temperature of 100°F. Milk averaged about 8.75 percent solids and 0.01 percent butterfat (Babcock). Milk was pumped (9) and metered (10) to the evaporator second and first-effect interstage heaters (11,12) installed in series with the product flow in that sequence. Milk was warmed in the interstage heaters to 145°F. and was used to condense vapors from the second and first-effect separators, respectively.

After leaving the first-effect interstage heater during grade "A" operations the milk went to a small, open, portable surge tank (17). From the surge tank, milk was pumped (13) to the live steam heater (14) where it was heated to 164°F. by live steam at 189°F. From the live steam



heater, milk was pumped (18) through a stainless steel holding tube (19) with a flow-diversion valve (20) at the outlet. This valve was set to divert at 161°F. and to open at 162°F. The sixteen second holding period was sufficient for pasteurization. Diverted milk returned to the surge tank while milk at the correct temperature went to the 850 gallon hot well (15) which served as the supply reservoir for the condensing operation.

For operations other than grade "A", milk was pumped (13) directly from the interstage heaters to the live steam heater (14) where it was heated to a range of from 158°F. to 195°F. depending upon the final product desired. Products and their representative temperatures upon leaving the live steam heater are as follows:

Cottage cheese grade	158°F.
Ice cream grade (or medium heat)	174°F.
High heat	190°F.
Baker's special (whey protein nitrogen not more than 1.0mgs. per gm.)	195°F.

Milk passed directly from the live steam heater to the hot well (15). All product operations were identical after location (15).

From the hot well the milk was pumped (16) through the first-effect liquid level valve (22) into the first-effect chest (23). The liquid level valve was vacuum operated and functioned automatically to regulate the level of fluid within the first-effect separator to the desired level by adjusting the flow of milk into the first-effect chest.

Milk was heated in the first-effect chest by a mixture of high-pressure steam and vapor from the thermo-compressor (21) at 100 PSIG. The thermo-compressor was designed to increase the efficiency of the evaporator by recapturing a major portion of the vapor leaving the first-effect separator. High-pressure motive steam from the boiler elevated the

first-effect vapor back to the temperature used in the first-effect chest, and thereby recovered the heat of the vapor from the first-effect separator for reuse.<sup>1</sup> This diversion of a portion of the first-effect vapor back into the first-effect chest was continuous throughout operation of the evaporator.

From the first-effect chest milk entered the first-effect separator (27) which operated under approximately sixteen inches of vacuum and a vapor temperature of 153°F. to evaporate moisture from the milk. Part of the vapors leaving the first-effect separator were recaptured by the thermo-compressor in the manner previously described.

A small portion of the remaining first-effect vapor was directed to the first-effect interstage heater (12) where it was used to warm the incoming milk and was thereby condensed. The major portion of the first-effect vapor went to the second-effect chest (29) where it was used to heat the second-effect. No boiler steam was used anywhere except in the first-effect chest. Each succeeding effect was heated by vapor from the separator of the preceding effect.

Product from the first-effect separator was withdrawn through the second-effect liquid level control valve (28) and into the second-effect chest (29) by the greater vacuum of the second effect. Milk was heated in the second-effect chest by vapor from the first-effect separator. Milk from the chest entered the second-effect separator (31) which operated under approximately twenty-four inches of vacuum and a vapor temperature of 139°F. to vaporize additional moisture from the milk. A small portion of vapor from the second-effect separator went to the second-effect interstage heater (11) with the major portion going to the third-effect chest (33).

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<sup>1</sup>See Table 6 in Part III.



Product from the second-effect separator was withdrawn through the third-effect liquid level control valve (32) and into the third-effect chest (33) by the greater vacuum of the third effect. Milk was heated in the third-effect chest by vapor from the second-effect separator. Milk from the chest entered the third-effect separator (35) which operated under approximately twenty-six inches of vacuum and a vapor temperature of 115°F. to vaporize additional moisture from the milk. A small portion of the vapor from the third-effect separator went to the third-effect vapor heaters (36,37) with the major portion going to the counter-current condensor (40).

By heating the milk for further processing and thereby condensing the vapor from the third effect, the third-effect vapor heaters served the same purpose as did the interstage heaters of the first and second effects. However, instead of warming milk that was incoming to the evaporator, the vapor heaters heated milk pumped (2) from the can-receiving room or from incoming bulk tankers. Incoming milk at 40°F. passed through both vapor heaters connected in series, leaving at a temperature of 100°F. It was then pumped (3,4) to the cream separator location to be separated.

Approximately 452 GPM. of water at about 90°F. was pumped (42) from the counter-current condensor (40) to the cooling towers (43,45) connected in parallel where two fans (44,46) were used to recool the water by evaporation. Tower number one (43) had a larger cooling capacity than did tower number two (45), and the temperature of the cooling water could therefore be regulated, to a certain degree, by the option of using neither, either, or both of the fans. Cooled water returned to the counter-current condensor by gravity aided by vacuum maintained in the condensor.

Steam jet air ejectors (39,41) were located at the condensor. Steam jet air ejectors were used to establish and maintain the desired vacuum in the condensor and thereby the evaporator. The second-stage



ejector (41) was popularly referred to as the "hogging jet" and operated to supplement the first-stage air ejector (39) in initially establishing the correct vacuum. During the remainder of the operation only the first-stage ejector, popularly referred to as the "intermediate jet", was operated to maintain the desired vacuum. Both air ejector stages were operated by high-pressure steam from the boiler.

Steam from operation of the first-stage ejector and the vapor exhausted from the third-effect separator were vented into the condensor. The condensate was added to the flow of cooling water and pumped to the towers. This addition was normally more than adequate to make up for loss of water by evaporation in the cooling towers. During initial operation use of the second-stage ejector "hogging jet", vapor was exhausted to the atmosphere.

Condensate from the various chests, interstage heaters, and vapor heaters was either pumped to the drain or was collected in a holding tank (25) for return to the boiler room to be reused as boiler feed water if carryover of milk solids from the evaporator was within tolerance. A turbidity detector (26) was used to constantly monitor condensate pumped to the holding tank and automatically dumped contents of the tank to the drain at any time carryover of milk solids exceeded tolerance limits for boiler feed water. This was the case at the beginning and end of each operation when the evaporator was not otherwise in normal operation.

Only condensate from certain sections of the evaporator was selected to go to the holding tank. The remaining condensate consistently contained excessive carryover and would thereby contaminate otherwise acceptable condensate. Condensate from the first-effect chest, second-effect interstage heater, and third-effect chest was pumped (24,34) to the holding tank. Condensate from the first-effect interstage heater,

second-effect chest, and third-effect vapor heaters was pumped (30,38) to the drain.

Condensed product was removed from the third effect with a variable-speed pump (47). Solids output was monitored continuously with a baume hydrometer floating in a stainless steel tube mounted above the hot well. Solids output of the evaporator was regulated to the desired 43 percent (baume reading of 21.5 and a product temperature of 110°F.), by adjusting the rate of product removal from the third effect by the variable speed removal pump.

During periods when the milk dryer was in operation, the product went directly to the dryer. At all other times the product was cooled in the plate heat exchanger (48) and was temporarily stored in the insulated storage vat (49). The product flow of this stage ended with the cooled condensed milk in the storage vat or the warm condensed milk at the dryer.

Product alternatives.--Condensed skim milk processed for use in cottage cheese grade, ice cream grade, high heat, or baker's special powder could either have been sold in ten-gallon cans, sold in bulk, or transferred to other processes within the plant where it could have been used in ice cream mix or dried.

## Stage II: Drying

Product flow.--This stage included all activities from the time condensed milk arrived at the dryer high-pressure feed pump until dry powder was in the bagging room spouts.

This stage began with the condensed milk at approximately 110°F. and 43 percent solids arriving at the high-pressure feed pump (51) from the evaporator product removal pump. The feed pump supplied condensed



product to the spray nozzles in the drying chamber (52) at a pressure of from 3,500 to 4,000 pounds per square inch (psi).

Air supply for the main drying system was pulled through a filter (53) by the intake fan (54) and directed toward the gas burner (57). A portion of the filtered air was diverted to the burner intake fan (55) which supplied air to the gas-air jets (56). Natural gas was used as fuel during the major portion of the year. Propane was used as fuel only during the coldest winter months when the natural gas line pressure became inadequate due to greater domestic requirements. It was assumed that natural gas was used exclusively in determining cost element requirements.

Combustion of the gas took place directly in the main burner air stream (57). The mixture of heated air and combustion products left the burner at a temperature of approximately 475°F. The temperature of the gases leaving the burner was the primary means of controlling the moisture content of the powder. The temperature of air being exhausted from the system was continuously monitored by the dryer control panel. The temperature of the gases at the burner was automatically raised or lowered by the control panel in order to produce the desired exhaust temperature and thereby the associated degree of drying.

Hot air from the burner passed through three venturies at the top of the drying chamber (52) where it was mixed with condensed milk sprayed from nozzles. Rapid expansion of air leaving the venturies contributed to the speed of moisture evaporation from the droplets. The size of droplets could be regulated by changing the nozzle size and the pump pressure. This in turn affected drying characteristics and particle size of the powder. Larger nozzles and lower pressures produced larger particles requiring relatively more heat for a given moisture level of the powder. Smaller nozzles and higher pressures produced smaller particles with savings



on energy requirements. It was found, however, that increased efficiency due to a reduction of heat requirements for the smaller droplets was attained at the expense of an increase in the loss of powder from the exhaust stack due to smaller powder particle size.

Spray nozzles in use at the time of this study were 0.080 inch in diameter with a 0.090 inch whizzer during regular operations. During periods when chilled condensed was being dried an orifice 0.075 inch in diameter with an 0.085 inch whizzer was used.

Milk dried as it fell to the bottom of the drying chamber where partially dried powder was entrained in the air stream which transported powder from the bottom of the drying chamber back up and introduced it into the two powder-air cyclonic separators (58,59) installed in parallel. Air was exhausted from the separators by the exhaust fan (84) at an average temperature of about 190°F. The exhaust fan was of larger capacity than the intake fan (53) which enabled the system to operate under a partial vacuum. This provision reduced the amount of powder escaping from the system into the surrounding plant during operation.

Powder was separated from the hot air by centrifugal force in the cyclonic separators (58,59) and left the bottom of the separators through airlocks (60,61). These airlocks assisted in maintaining the partial vacuum by controlling the air flow. After leaving the separator airlocks, powder dropped directly into the individual powder redriers (62,63), located under each separator. Hot air from the redrier burner (65) was introduced at this point to further dry the powder.

The redrier burner was constructed with three separate burners which could be individually regulated. Air heated by the first burner was used in redriers (62,63) on the two powder-air separators (58,59). Air from the second burner went to the redrier (68) on the first powder

collector (66) and air from the third burner went to the redrier (71) on the second powder collector (69). This arrangement permitted the burners to the redriers on the powder collectors to be adjusted independently of the burner to the redriers on the separators. If either or both of the second and third burners were not needed in order to bring the moisture content down to the desired level, they were turned off and the redrier on that powder collector would then function in the same manner as the powder coolers.

Motive air for transportation of the powder through the remainder of the system was supplied by the transfer fan (83). The transfer fan also maintained a vacuum on all five powder collectors. Powder in the redriers of the powder-air separators was entrained in this airflow and moved to the top of powder collector number one. Here air was exhausted by the transfer fan and powder dropped through the air lock (67) into powder redrier number three (68). Again hot air from the redrier burner was introduced and powder moved to powder collector number two (69).

All five powder collectors were of identical construction and function and were mounted in series. Variations at each stage occurred only in substitution of powder coolers (74,78) in the place of redriers on powder collectors three (72) and four (76). Powder coolers introduced filtered (75,79) air at room temperature to cool the powder before the bagging operation. Powder collector number five (80) had neither cooler nor redrier. Dry cooled powder passed directly to the airlock (81) and entered the cyclocentric sifter (82) by gravity.

The cyclocentric sifter used two screens with different size apertures. The top screen was relatively coarse with 135 openings per square inch for screening lumps and foreign material from the powder. Any material thus removed went to spout number three in the bagging room as



reject powder. The second screen was less coarse with 175 openings per square inch and was inserted only during operations in which it was desirable to save the relatively larger particles in the powder for sale as "instant" powder. Instant powder went to spout number two.

During "instant" operations, all remaining powder went to spout number one. If no "instant" powder was desired, the second screen was removed and all powder passing through the first screen went to spout number one.

The stage ended with screened powder in the bagging room spouts.

Product alternatives.--The final moisture content of the powder can be varied in the redriers. "Extra" grade powder must have a moisture content less than 4.0 percent. "Government" grade powder must have a moisture content not greater than 3.5 percent. The moisture content remained in the vicinity of 3.5 percent during the period covered by this study.<sup>1</sup>

Milk particles of the size necessary to be classified as "instant" could either be screened out and delivered to the bagging room separately in spout number two, or combined with the remainder of the powder in spout number one.

### Stage III: Bagging

Product flow.--This stage included all activities from the time dry milk left the spouts in the bagging room, until the sealed containers were in place on a stack in temporary storage.

This stage began with powder in the three spouts from the sifter. These spouts entered the bagging room from overhead. Both number two "instant" spout and number one "fines" spout could be equipped with a

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<sup>1</sup>See Table 43 in Appendix E.



two-way valve to facilitate continuous filling. During operations when instant powder was being produced, it was necessary to bag both "instant" and "fines" since only about twenty percent of the powder was in flakes large enough to be classified as "instant".

A vacuum exhaust from each bagging spout was used to prevent loss of powder into the atmosphere during bagging by exhausting air from the bags as they were filled and returning the airborne powder to the transfer fan (83). A clear plastic bag liner was attached to the bottom of the reject spout. Normally such a small amount accumulated during the working day that it did not have to be changed.

Bags were filled manually and timed by the sweep second hand of a wall clock located above the spouts. Samples of powder were taken from the bags before weighing and moisture tests were made with the moisture balance tester (95) located in the bagging room. Tests were more frequent during production of government grade powder than during normal commercial processing.

The bag was hand-lifted from the filling spout onto the platform scales (93) where it was weighed and equalized to the desired weight using powder from an extra bag placed at the scales. The inner plastic liner was tied with a string and the top of the paper bag sewed with a sewing machine (94) suspended from the ceiling.

Sealed bags were stacked upon wooden pallets which had been placed on the floor of the bagging room. A total of 36 fifty-pound or 15 hundred-pound bags were placed on each pallet. The pallet was removed from the bagging room by means of an electric forklift (98) and transported to the stack in the temporary storage areas. Bags remained on the pallet and the pallet was lifted onto the stack. The forklift was then shuttled back to the bagging room.

This stage ended with the pallet and sealed containers in place on the stack.

Product alternatives.--Dry milk could be packaged in the following size containers (for purposes of this study):

- A. Fifty-pound plain bags;
- B. Hundred-pound bags:
  - 1. Plain;
  - 2. Government specification.

#### Stage IV: Storage

Product flow.--This stage included all temporary storage of the sealed containers from the time the pallets were stacked in place until such time as the pallets were again removed for further transfer. There was no processing of the product in this stage other than the provision for "time" utility. This stage ended with the pallet still in place on the stack just prior to being removed for further transfer.

Product alternatives.--Dry milk in the sealed containers could have entered either of the following alternative uses:

- A. Sold as dry milk powder;
- B. In-plant transfers of milk powder.

#### Stage V: Truck loading

Product flow.--This stage included all handling of the sealed powder containers from the time the pallet was removed from the temporary storage stack until the bags were in place in the truck for transportation to their destination.

This stage began with the full bags of milk powder stacked in place on pallets in the storage area. The electric forklift removed the pallets

from the stack and transported them to the loading dock. Bags were removed from the pallet by hand and stacked individually in the truck.

Maximum load for the semi-trailer trucks being used was 31,000 pounds. This is equivalent to 620 fifty-pound bags or 310 hundred-pound bags. No preparation of the truck was usually required for transportation of bagged powder. This stage ended with the bags of milk powder positioned in the truck.

Product alternatives.--The only alternative for this stage was shipment of the milk powder by truck.

#### Stage VI: Railroad car loading

Product flow.--This stage included all handling of the sealed powder containers from the time the pallet was removed from the temporary storage stack until the bags were positioned in the railroad car. It also included all of the activities necessary in preparing the railroad car for transportation of the powder bags.

This stage began with the full bags of milk powder stacked in place on pallets in the storage area. The electric forklift removed the pallet from the stack, transported it to the loading dock and deposited it in the truck while still loaded. When the truck was almost fully loaded, the forklift was left in the truck and the load was driven to the railroad loading dock.

The forklift removed the pallets from the truck and placed them in the railroad car. Bags were removed from the pallet and stacked in the railroad car by hand. During periods in which the truck returned to the plant for reloading, the remaining crew prepared the car. The interior was sprayed with insecticide, protruding nails were removed and rough places were covered with cardboard. The sides were lined with felt roofing



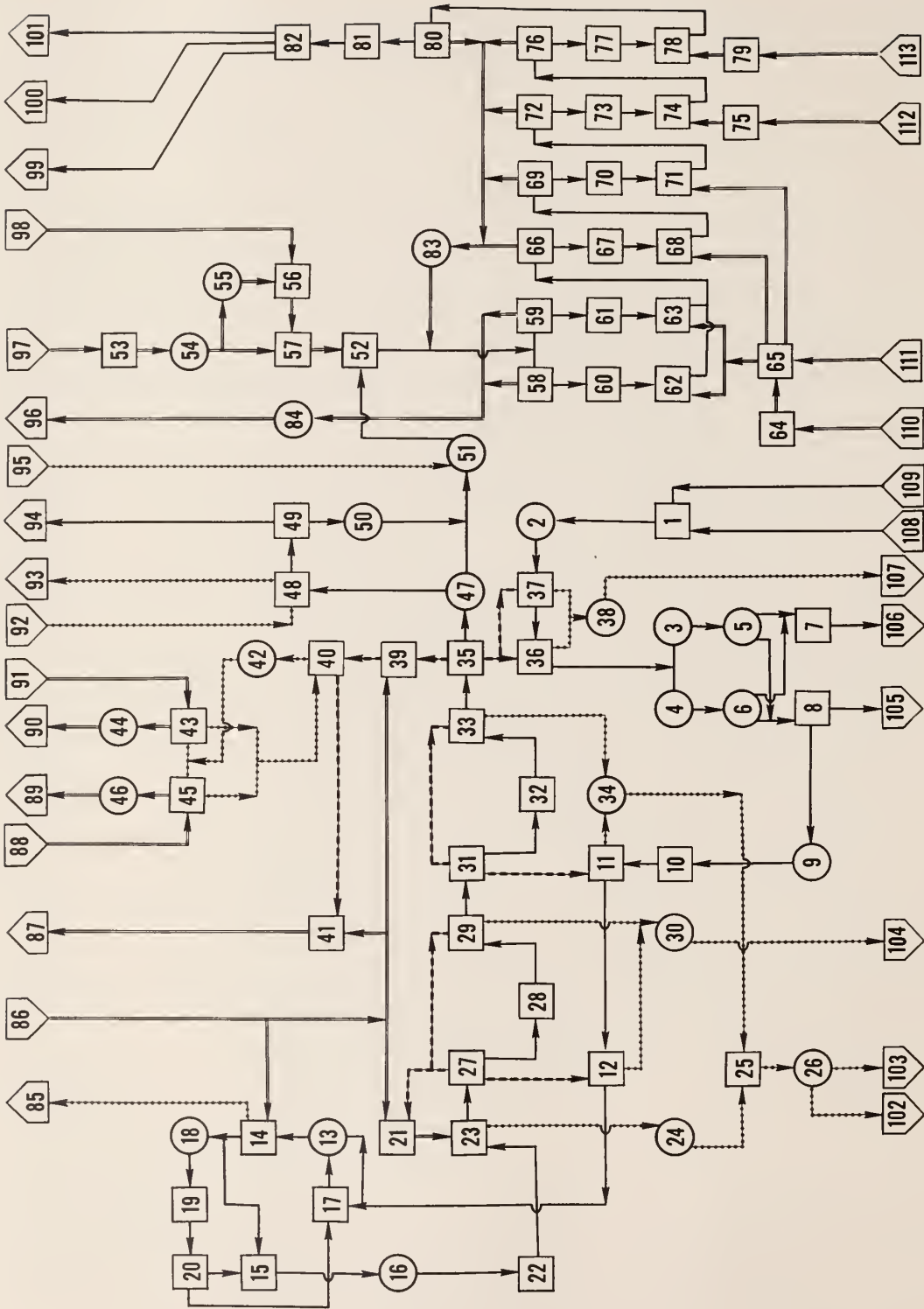


Fig. 9.---Flow diagram for the evaporating, drying, and bagging stages of the model plant.

paper and the doors were boarded up. This stage ended with the bags of milk powder positioned in the railroad car.

Product alternatives.---The only alternative for this stage was shipment of the milk powder by railroad car.

TABLE 39.---Identification of model plant equipment presented in Figure 9

Key	Item	Key	Item
1.	Whole milk storage vat	18.	Holding tube pump and motor
2.	Vapor heater milk supply pump and motor	19.	Grade A holding tube
3.	Cream separator milk transfer pump and motor no. 1	20.	Flow diversion valve
4.	Cream separator milk transfer pump and motor no. 2	21.	Thermo-compressor
5.	Cream separator no. 1	22.	1st-effect liquid level valve
6.	Cream separator no. 2	23.	1st-effect chest
7.	Cream storage vat	24.	1st-effect chest condensate pump and motor
8.	Skim milk storage vat	25.	Condensate reservoir
9.	Evaporator milk supply pump and motor	26.	Turbidity detector and valve
10.	Evaporator input flow meter	27.	1st-effect separator
11.	2nd-effect interstage heater	28.	2nd-effect liquid level valve
12.	1st-effect interstage heater	29.	2nd-effect chest
13.	Live steam heater pump and motor	30.	2nd-effect chest and 1st-effect interstage heater condensate pump and motor
14.	Live steam heater	31.	2nd-effect separator
15.	Hot well	32.	3rd-effect liquid level valve
16.	Hot-well pump and motor	33.	3rd-effect chest
17.	Grade A surge tank	34.	3rd-effect chest and 2nd-effect interstage heater condensate pump and motor

TABLE 39.--Continued

Key	Item	Key	Item
35.	3rd-effect separator	54.	Air intake fan and motor
36.	3rd-effect vapor heater no. 1	55.	Gas burner fan and motor
37.	3rd-effect vapor heater no. 2	56.	Gas-air jets
38.	3rd-effect vapor heaters condensate pump and motor	57.	Gas burner
39.	Intermediate steam jet air ejector	58.	Powder-air separator no. 1
40.	Counter-current condensor	59.	Powder-air separator no. 2
41.	Steam jet air ejector (hogging jet)	60.	Airlock and motor no. 1
42.	Condensor pump and motor	61.	Airlock and motor no. 2
43.	Cooling tower no. 1 (large)	62.	Powder redrier no. 1
44.	Cooling tower no. 1 fan and motor	63.	Powder redrier no. 2
45.	Cooling tower no. 2 (small)	64.	Redrier air heater intake filter
46.	Cooling tower no. 2 fan and motor	65.	Redrier air heater
47.	Product removal pump and motor	66.	Powder collector no. 1
48.	Cooling plate	67.	Airlock and motor no. 3
49.	Condensed milk storage vat	68.	Powder redrier no. 3
50.	Portable transfer pump and dryer cleanup pump and motor	69.	Powder collector no. 2
51.	Dryer high pressure feed pump and motor	70.	Airlock and motor no. 4
52.	Drying chamber	71.	Powder redrier no. 4
53.	Air intake filter	72.	Powder collector no. 3
		73.	Airlock and motor no. 5
		74.	Powder cooler no. 1
		75.	Powder cooler no. 1 air filter
		76.	Powder collector no. 4
		77.	Airlock and motor no. 6



TABLE 39.--Continued

Key	Item	Key	Item
78.	Powder cooler no. 2	82.	Cyclocentric powder sifter and motor
79.	Powder cooler no. 2 air filter	83.	Transfer fan and motor
80.	Powder collector no. 5	84.	Exhaust fan and motor
81.	Airlock and motor no. 7		

## APPENDIX C

## Production Run Description by Phases

A detailed description of the various production run phases in each stage will be presented in this section. Definition of phase boundaries was intended to be coincidental with observed changes in cost element requirements occurring during progress of the production run. In this manner these production run subdivisions are of use for cost element requirement calculations in Appendix H. Table 40, at the end of this appendix, summarizes the periods of time assigned to the individual phases.

Stage I: Evaporating

Hookup phase.--This phase was defined as "fixed" for a production run and assigned an elapsed time of two and one-half hours. This phase included activity from the time that the evaporator operator reported to the evaporator at the start of a production run until the decision was made to open the steam valve to the hogging jets to initiate the vacuum buildup. Cost elements required during this phase were class A labor, electricity, water and chlorine.

The night cleanup man left the evaporator with the bottoms of the chests closed and the tops open. All CIP lines had been disconnected and sprayers had been removed.

The start-up man (class A labor) checked the chests to determine if any further time must be spent in further cleaning of tubes. After completing any additional work that might be required on the tubes, the

start-up man sprayed the insides of the chests and separators with a mixture of chlorine and water. The product removal pump was run briefly to remove any of the residual chlorine and was run to the vat which was to receive the condensed product.

The start-up man then disassembled and washed the hot-well pump, live steam heater pump and the input pump. At this point the operator was ready to start building the vacuum in the evaporator.

Vacuum buildup phase.---This phase was defined as "fixed" for a production run and assigned an elapsed time of forty-five minutes. This phase included activity from the time that the decision was made to open the steam valve to the hogging jets until the decision was made to open the main steam valve to the thermo-compressor. Cost elements required were class A labor, electricity and steam.

In order to start building the vacuum in the evaporator, the operator (class A labor) circulated cooling water through the condensor with the condensor circulating pump. Steam was simultaneously started to the hogging jets and the intermediate air-ejector jets. Vacuum was increased to about twenty-four inches before steam and milk were started to the live steam heater. After the hot well was full and the vacuum had reached twenty-five inches, the point of decision for commencing the warm-up phase had been reached. If it was still too soon for the day's operation to commence, the evaporator could be held in this state of readiness for a short period. For purposes of this study it was assumed that there was no delay and processing always continued directly into the warm-up phase at this point.

Warm-up phase.---This phase was defined as "fixed" for a production run and assigned an elapsed time of thirty minutes. This phase included activity from the time that the decision was made to open the main steam



valve to the thermo-compressor until the decision was made to start the product removal pump when the condensed product had finally reached the desired concentration. Cost elements required were class A labor, electricity, and steam.

With a vacuum in the evaporator of at least twenty-five inches the operator (class A labor) started the steam to the thermo-compressor to initiate evaporation in the evaporator. A period of time was required to bring the condensed product down to the desired concentration before the product removal pump was started to remove condensed product. The operator checked the product after a short period of time and the decision to initiate product removal was made if the product was at a concentration greater than about thirty-six percent solids. This phase terminated with the decision to initiate removal of the product.

Operating phase.---This phase was defined as "variable" for a production run. Elapsed time assigned to this phase was assumed to be directly proportional to the quantity of final product processed. This relationship could be expressed approximately as 0.0287202536 hour required for each one hundred pounds of powder processed.<sup>1</sup>

This phase included activity from the time the decision was made to start the product removal pump until the steam valve to the live steam heater was closed at the termination of processing. Cost elements required were class A labor, electricity and steam.

The product removal pump was started by the operator (class A labor) when the condensed product was at approximately thirty-six percent solids. The removal rate was slow at the start of the operation period but product concentration was gradually raised as the operation proceeded.

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<sup>1</sup>See Table 41, Appendix D.

Adjustments in product concentration made by decreasing the rate of product removal tended to increase the concentration of the product. Adjustments to the product concentration were continued by varying the rate of product removal until normal operation was reached with a concentration of approximately forty-three percent solids.

The product can be further varied during the operating phase by adjusting the temperature of the skim milk leaving the live steam heater. These are the only alterations that can be made in the final product during the operating phase. This phase terminated with the decision to discontinue the steam supply to the pre-heater at the end of the processing period.

Shutting-down phase.--This phase was defined as "fixed" for a production run and assigned an elapsed time of forty minutes. This phase included activity from the time that the steam valve to the live steam heater was closed until the product removal pump was stopped after removal of all fluid milk from the last effect. Cost elements required during this phase were class A labor, electricity, steam and water.

As steam to the live steam heater was terminated by the operator (class A labor), the evaporator was switched over to receive clear water in order to flush out lines from the vats to the hot well. After flushing these lines water flow was terminated and the hot well emptied. The length of time required to empty the hot well was determined by the quantity of skim milk actually in the hot well at this point. It required ten minutes to remove 800 gallons of milk (8.64 lbs. per gal.) from the hot well at a rate of 39,090 pounds per hour.

When the hot well was completely empty, the air supply to the control panel was shut off. This opened the liquid level control valves



between the three effects and equalized the level of liquid among all three. The operator continued to monitor the level of liquid within the separators until it dropped to the danger point at which time steam to the thermo-compressor was terminated. The product removal pump continued to run in order to remove from the evaporator remaining liquid not yet down to the normal concentration. This phase terminated with shutdown of the product removal pump after removal of all liquid from the evaporator.

Cleanup phase.--This phase was defined as "fixed" for a production run and assigned an elapsed time of eight hours. This phase included all activity from the time that the product removal pump was stopped after removal of all fluid milk from the last effect until the cleanup man departed from the evaporator leaving bottoms of the chests closed and tops of the chests open. Cost elements required during this phase were class A labor, electricity, steam, water, LC-10 acid cleaner, and alkali cleaner.

The first step in the cleanup stage required the cleanup man (class A labor) to assemble the CIP plumbing throughout the evaporator and to ready the evaporator for circulation. Two CIP pumps were connected, sprayers were placed inside the chests and separators, and the product removal pump was dismantled. Four periods of circulation during the cleanup period and their approximate lengths are as follows:

- |                       |             |
|-----------------------|-------------|
| 1. Alkali circulation | 2 hours,    |
| 2. Clear rinse        | 45 minutes, |
| 3. Acid circulation   | 1 hour, and |
| 4. Clear rinse        | 30 minutes. |

Periods of time allowed for the alkali circulation varied somewhat according to condition of the tubes in the chests after the processing period. To a certain extent these periods were also altered from night to



night to fit in with other activities required of the cleanup man. After the second clear rinse, bottoms of the chests were opened and tubes inspected in order to detect accumulation of deposits. Tubes requiring additional attention were cleaned with a wire brush on a rod in order to remove deposits. The night cleanup man left the evaporator with bottoms of the chests closed and tops open.

## Stage II: Drying

Hookup phase.--This phase was defined as "fixed" for a production run and assigned an elapsed time of ten minutes. This phase included activity from the time the dryer operator reported to the dryer at the start of a production run until the decision was made to start the fans to initiate warm-up. The only cost element required was class A labor.

The night cleanup man reassembled the dryer and left it essentially ready to start operation. The operator (class A labor) reported to the dryer area at the beginning of a production run and made a trip to the top of the drying chamber for visual inspection of equipment and to check the water level in the reservoir that cooled the venturries. After this preliminary inspection the operator returned to the main control panel and was ready to start the fans.

Warm-up phase.--This phase was defined as "fixed" for a production run and assigned an elapsed time of twenty minutes. This phase included activity from the time the decision was made to start the fans until the decision was made to switch the high-pressure feed pump over from pumping water to pumping condensed product. Cost elements required included class A labor, electricity, natural gas, and water.

To initiate the dryer warm-up, fans were started by the operator (class A labor) and allowed to run briefly in order to clear any possible

accumulation of gas from the drying chamber before the gas burner was lit. Temperature in the drying chamber was allowed to rise to about 180°F. The high-pressure pump was started at this point in order to pump water to the drying chamber at about 1,500 to 2,000 pounds per square inch (psi).

Pumping water into the drying chamber forced the gas burner to open and increase the temperature of the intake air up to the designed 475°F. This practice seemed to prove more satisfactory for drying the interior of the equipment than did a warm-up period without pumping water to the chamber. If any area in the interior was not thoroughly dry before operation was started, powder would stick and accumulate. As the exhaust temperature of the system approached 210°F., air-lock motors and the sifter were started and the dryer was ready for the operating phase.

Operating phase.--This phase was defined as "variable" for a production run. Elapsed time assigned to this phase was assumed to be directly proportional to the quantity of final product processed. For this phase 0.0287202536 hour was required per hundred weight of powder processed.<sup>1</sup>

This phase included activity from the time the decision was made to switch the high-pressure feed pump over from pumping water to pumping condensed product until the decision was made to switch back again to pumping water at the close of processing. Cost elements required included class A labor, electricity and natural gas.

At the decision by the operator (class A labor) to begin processing, the high-pressure pump was switched over from pumping water to receiving condensed product from either the evaporator or a vat. The pressure of the pump was also increased to about 3,500 to 4,000 psi at this point.

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<sup>1</sup>See Table 41, Appendix D.



The operator remained at the dryer only an estimated five minutes of each operating hour. On each trip to the dryer area the operator would make a brief check of the control panel, check to note that all airlocks were functioning and to see that there was no indication of a developing blockage. Adjustments to the redrier burners were also made in order to control the final moisture content of the powder being bagged. The remainder of the operator's time was spent in the bagging room.

This phase ended with the decision to terminate flow of condensed product to the dryer at the close of processing.

Shutting-down for maintenance phase.--This phase was defined as "variable" for a production run. Elapsed time assigned to this phase was assumed to be directly proportional to the quantity of final product produced.<sup>1</sup> For this phase 0.0001292411 hour was required per hundredweight of powder produced during five-day weeks, or 0.0002728424 hour per hundredweight of powder produced during six-day weeks.<sup>2</sup> This phase included activity from the time the decision was made to switch the high-pressure feed pump over from pumping condensed product to pumping water until the fans and sifter were shut off. Cost elements required included class A labor, electricity, natural gas, and water.

A total of five minutes was usual for a single shutting-down for maintenance period although actual time required for a particular instance could vary considerably. In situations where it would be necessary to work on spray nozzles at the top of the drying chamber it was necessary to cool the drying chamber considerably more than would be the case otherwise. The manner in which this phase was analyzed is discussed in Appendix G.

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<sup>1</sup>See analysis of dryer down time in Appendix G for reasoning leading to this proportionality assumption.

<sup>2</sup>See Table 41, Appendix D.



General progress of this phase was quite similar to the regular shutting-down phase. The dryer operator diverted flow of condensed product from the evaporator to run through a cooling plate to a storage vat and the high-pressure feed pump was switched over to pump water at about 1,500 psi. Burners were switched over to manual control and reduced to their lowest flame level. After about two minutes the high-pressure feed pump was stopped and the burners shut off. After another two to three minutes the fans and sifter were shut off and this phase was terminated.

Downtime for maintenance phase.--This phase was defined as "variable" for a production run. Elapsed time assigned to this phase was assumed to be directly proportional to the quantity of final product processed. For this phase 0.0006663099 hour was required per hundred-weight powder produced during five-day weeks, or 0.0015394056 hour per hundredweight of powder produced during six-day weeks.<sup>1</sup> This phase included maintenance activity from the time the fans and sifter were shut off until the decision was made to start the fans again for the subsequent warm-up. Cost elements required included classes A, B, and C labor.

This phase contained the dryer maintenance activity. The dryer operator, plus personnel assigned to the bagging stage, corrected deficiencies that had caused the interruption.

Common causes for downtime were stoppages at the bases of powder-air separators, plugging of spray nozzles and burning of powder onto the top of the drying chamber. In situations where it was desirable to switch from regular to instant powder during the day, it was necessary to stop processing in order to install or remove the sifter screen used for instant powder. Time required for any particular instance of downtime

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<sup>1</sup>See Table 41, Appendix D.

varied according to type of maintenance required and severity of the particular instance.

This phase terminated when the fans were restarted to begin the warm-up.

Warm-up after downtime phase.--This phase was defined as "variable" for a production run. Elapsed time assigned to this phase was assumed to be directly proportional to the quantity of final product processed. For this phase 0.0002556103 hour of this phase was required per hundredweight of powder produced during five-day weeks, or 0.0005484468 hour per hundredweight of powder produced during six-day weeks.<sup>1</sup> This phase included activity from the time the decision was made to restart the fans until the decision was made to switch the high-pressure feed pump over from pumping water to pumping condensed product. Cost elements required included class A labor, electricity, natural gas, and water.

A total of ten minutes was assigned for a single "warm-up after downtime phase." General nature of this phase was quite similar to the regular warm-up phase. Fans were started and allowed to run briefly to clear any possible accumulation of gas from the drying chamber before the gas burners were lit. Temperature in the drying chamber was allowed to rise to about 180°F. Then the high-pressure pump was started in order to deliver water to the sprayer nozzles at about 1,500 psi. Since the system was already warm from previous operation, this warm-up phase did not require as long a period of time as required during the regular "warm-up" phase. This phase terminated when the high-pressure pump was switched over to receive condensed milk from the evaporator.

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<sup>1</sup>See Table 41, Appendix D.



Shutting-down phase.--This phase was defined as "fixed" for a production run and ten minutes elapsed time was assigned. This phase included activity from the time the decision was made to switch the high-pressure feed pump over from pumping condensed product to pumping water until all fans were shut off. Cost elements required included class A labor, electricity, natural gas, and water.

When flow of condensed product to the dryer was terminated, the high-pressure pump was switched back to water again at about 1,500 psi. Gas burners were switched over to manual control and reduced to their lowest flame level. The high-pressure pump was stopped and gas to the burners and the redrier was shut off. Fans, air-lock motors and sifter continued to operate for approximately another eight minutes until all powder was extracted from the system and temperature of the drying chamber had dropped below 150°F. When the temperature was cool enough, all fans and motors were shut off and the shutting-down phase was terminated.

Cleanup phase.--This phase was defined as "fixed" for a production run and three and one-half hours elapsed time was assigned. This phase included activity from the time the dryer fans were shut off until the cleanup man departed from the dryer. Cost elements required class A labor, electricity, water, Shur-spray acid cleaner, and alkali cleaner.

Cleanup began with removal of the exhaust elbow at the base of the drying chamber by the night cleanup man (class A labor). Any collection of powder found in the elbow was removed. The pipe line carrying condensed product from the evaporator was rinsed with clear water.

A 200-gallon tank was positioned beneath the drying chamber and filled with about 150 gallons of clear water. A canvass skirt was attached to the bottom of the drying chamber to control the spray during cleanup. The ten horsepower circulating pump was connected to the CIP



plumbing at the tank below the drying chamber. A trip to the top of the drying chamber was necessary in order to insert the spray head and to connect it to the CIP plumbing.

First rinse with clear water required about ten minutes. Water was then drained and the tank was filled with about sixty gallons of hot water. Approximately one gallon of Shur-spray and one gallon of HC-90 were added to the tank and this combination was circulated for forty-five minutes.

During this period of circulation the cleanup man was concerned with other equipment associated with the dryer. During each cleanup, two of the twenty filter units for the intake filter were removed and the filter material renewed. On alternate nights either the three spray nozzles were cleaned or the high-pressure pump was disassembled. When cleaning the nozzles, the six-foot extensions of pipe positioning the three nozzles in the venturies at the top of the drying chamber were removed. Nozzles were disassembled and cleaned and a wire brush run through the pipe. When the high-pressure pump was disassembled, two of the four pressure packings were renewed on each of the three pistons.

The high-pressure pump was started in order to pump clear water through the nozzles for the final twenty-five minutes of this rinse. Then the cleaning solution was drained and a third rinse with about 150 gallons of clear water was made for another fifteen minutes without the high-pressure pump. This rinse water was drained and the tank was removed from beneath the drying chamber. The skirt was removed and the circulating pump was disconnected. The CIP plumbing was disconnected and the spray head was removed from the top of the drying chamber.

After a general cleanup of the drying area the elbow was replaced and attached to the base of the drying chamber and the dryer was ready for

operation at the close of this phase.

### Stage III: Bagging

Setup phase.---This phase was defined as "fixed" for a production run and twenty minutes elapsed time was assigned. This phase included activity from the time that the bagging man (or men) reported to the bagging room until the decision was made to switch the dryer high-pressure feed pump over from pumping water to pumping condensed product. Cost elements required included classes B and C labor.<sup>1</sup>

When workers reported to the dryer location, equipment in the bagging room was put into position and made ready for the bagging operation. A clear plastic bag was attached to the "reject" or "third-grade" spout from the sifter. The metal platform for supporting the bags during filling was positioned under the spouts. Scales were positioned and the sewing machine checked. String bag-ties were provided at the scales. Empty bags were brought from storage and a stencil cut for identifying the powder production to follow. The forklift was used to bring an initial supply of empty pallets and the remaining time before the start of processing was used to stencil empty bags.

If there was to be a switch from production of "regular" to "instant" powder, or vice versa with respect to the preceding production run, it was also necessary to either insert or to remove the "instant" screen at the sifter and to attach or remove the "instant" spout in the bagging room. This phase terminated at the time the dryer high-pressure pump was switched over to receive condensed product.

Operating phase.---This phase was defined as "variable" for a production run. Elapsed time assigned to this phase was assumed to be

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<sup>1</sup>See operating phase of the bagging stage for labor requirements.



directly proportional to the quantity of final product processed. For this phase 0.0287202536 hour was required per hundredweight of powder processed.<sup>1</sup>

This phase included activity from the time the decision was made to switch the dryer high-pressure feed pump over from pumping water to pumping condensed product until the decision was made to switch the pump back again from condensed product to water. Cost elements required included classes A, B, and C labor, electricity, fifty-pound plain bags, hundred-pound plain bags, and hundred-pound government bags.

Labor requirements of this phase were different for operations with fifty-pound bags than they were for operations with hundred-pound bags. During hundred-pound bag operations, one class B labor man was assigned to the bagging room. Since fifty-pound bag operations required handling twice as many bags, an additional class C labor man was assigned. During both operations the dryer operator (class A labor) was in the bagging room for about fifty-five minutes during each hour.

The filling operation for bags was timed with the sweep-second hand of an electric clock. The bag was then hand-lifted to platform scales and equalized to the desired weight by adding or removing powder. An extra, open bag of powder was positioned alongside the scales for this equalization.

The inner plastic liner of the bag was tied with a pre-cut string and the top of the bag sewed with the sewing machine. Bags were again hand-lifted and positioned upon the pallet. A pallet load consisted of 15 hundred-pound bags or 36 fifty-pound bags.

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<sup>1</sup>See Table 41, Appendix D.



When a pallet was completely filled it was taken to the storage area by the forklift and stacked. Periodic powder samples were taken and checked for moisture content. Additional bags were stenciled as they were needed. This phase ended when the dryer high-pressure pump was switched back to pump water.

Shutting-down for dryer maintenance phase.--This phase was defined as variable for a production run. Elapsed time assigned to this phase was assumed to be directly proportional to the quantity of final product processed. For this phase 0.0001292411 hour was required per hundredweight powder produced during five-day weeks, or 0.0002728424 hour per hundredweight of powder produced during six-day weeks.<sup>1</sup>

This phase included activity from the time the decision was made to switch the dryer high-pressure feed pump over from pumping condensed product to pumping water until the dryer fans and sifter were shut off. Cost elements required included classes B and C labor and electricity.

A total of five minutes was assigned to a single "shutting-down for dryer maintenance" phase. The general nature and labor requirements of this phase were identical to the regular shutting-down phase. Personnel who remained in the bagging room continued to perform the same activities as during the operating phase. This phase ended when the dryer fans and sifter were shut off.

Downtime for dryer maintenance phase.--This phase was defined as "variable" for a production run. Elapsed time was assumed to be directly proportional to the quantity of final product processed. For this phase 0.0006663099 hour was required per hundredweight of powder produced during five-day weeks, or 0.0015394056 hour per hundredweight of powder produced

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<sup>1</sup>See Table 41, Appendix D.

during six-day weeks. This phase included activity from the time that the dryer fans and sifter were shut off until the decision was made to start the fans again for subsequent warm-up. No cost elements were required during this phase. However, during this period the bagging personnel were actually engaged in whatever maintenance was required by the dryer. This phase ended when the dryer fans were restarted to begin the dryer warm-up.

Warm-up after dryer downtime phase.--This phase was defined as "variable" for a production run. Elapsed time was assumed to be directly proportional to the quantity of final product processed. For this phase 0.0002556103 hour was required per hundredweight of powder produced during five-day weeks, or 0.0005485568 hour per hundredweight of powder produced during six-day weeks.

This phase included activity from the time that the decision was made to restart the dryer fans until the decision was made to switch the dryer high-pressure feed pump over from pumping water to pumping condensed product. Cost elements required included classes B and C labor.

A total of ten minutes was assigned to a single "warm-up after dryer downtime" phase. Bagging room operations performed during this phase were the same as during the regular "warm-up" phase. This phase ended when the dryer high-pressure pump was switched over to receive condensed milk from the evaporator.

Shutting-down phase.--This phase was defined as "fixed" for a production run and ten minutes elapsed time was required. This phase included activity from the time the decision was made to switch the dryer high pressure feed pump over from pumping condensed product to pumping



water until the dryer fans and sifter were shut off. Cost elements required included classes B and C labor and electricity.

This phase contained the same activities as the operating phase with the exception that the dryer operator had returned to the dryer. The phase ended when the fans and sifter were shut off.

Cleanup phase.--This phase was defined as "fixed" for a production run and an elapsed time of twenty minutes was required. This phase included activity from the time the dryer fans and sifter were shut off until the cleanup man left the bagging room. Cost elements required were class A labor and water.

The cleanup man (class A labor) moved the equipment out of the bagging room and hosed down the walls and equipment with water. Powder which had stuck to the floor was scraped up and the floor of the bagging room and adjacent area was hosed. This phase terminated when the cleanup man finished hosing the floor and had returned the equipment to the bagging room.

#### Stage IV: Storage

There were no phases defined to be "fixed" for this stage.

Operating phase.--This phase was defined to be "variable" for a production run but elapsed time was not directly related to production. No activities were included in this phase except for provision of "time utility." No cost elements were required during this phase (interest on powder in storage was not considered although insurance premiums are considered as a part of annual fixed expenses).

This phase provided storage time necessary to accumulate shipments of powder. For definitional purposes it included elapsed time from the



point at which the loaded pallet was placed in position upon the storage area stack until it was removed again for shipment.

#### Stage V: Truck loading

There were no phases defined to be "fixed" for this stage.

Operating phase.--This phase was defined to be "variable" for a production run. Fifty-five minutes were required to load 31,000 pounds of powder or 0.0029677419 hour of this phase was required for hundred-weight of powder loaded into trucks.

This phase included activity from the time the decision was made to remove the loaded pallet from storage with the forklift until the individual bags were in place in the truck. Cost elements required included classes A, B, and C labor.

Three men (one each classes A, B and C labor) required approximately fifty-five minutes to load a truck with 620 fifty-pound bags or 310 hundred-pound bags. One man transferred pallets with the forklift from the stack to the truck at the dock while the remaining two men removed the bags from the pallets and stacked them in the truck. This phase ended with the individual bags loaded in place in the truck.

#### Stage VI: Railroad car loading

There were no phases defined to be "fixed" for this stage.

Operating phase.--This phase was defined to be "variable" for a production run. Five hours were required to load 80,000 pounds of powder or 0.0062500000 hour of this phase was required per hundredweight of powder loaded railroad cars.

This phase included activity from the time the decision was made to remove the loaded pallet from storage with the forklift until the individual bags were in place in the railroad car. Cost elements required

included classes A, B, and C labor, insecticide, felt roofing paper, and one-by-four pine lumber.

For rail shipment six men (one each classes A and B, and four class C labor) were required for five hours to load a railroad car with 800 hundred-pound bags. Since there was no rail siding adjacent to the plant it was necessary for two men to load the pallets into a truck with the forklift and transfer them to the railroad car at a siding. While the truck was being loaded at the plant, the remaining four men cleaned the railroad car removing protruding nails, boarding the car doors, spraying with insecticide, and lining walls with cardboard and roofing paper.

Each truck-load from the plant contained thirteen pallets for a total of 195 hundred-pound bags and the forklift. Pallets were then transferred from the truck to the railroad car with the forklift and individual bags were stacked in the car. This phase ended with the individual bags loaded in place in the railroad car.

TABLE 40.--Periods of time assigned to the model plant fixed and variable production run phases<sup>a</sup>

Phases (m)	Stages (k)					
	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6
	5-day weeks					
m = 1	. . . . .	2.5000000000	hours	---	---	---
m = 2	. . . . .	0.7500000000	---	---	---	---
m = 3	. . . . .	0.5000000000	0.3333333333	---	---	---
m = 6	. . . . .	0.0287202536	0.0287202536	---	0.0029677419	0.0062500000
m = 7	. . . . .	---	0.0001292411	---	---	---
m = 8	. . . . .	---	0.0006663099	---	---	---
m = 9	. . . . .	---	0.0002556103	---	---	---
m = 4	. . . . .	0.6666666667	0.1666666667	---	---	---
m = 5	. . . . .	8.0000000000	0.3333333333	---	---	---
	6-day weeks					
m = 1	. . . . .	2.5000000000	hours	---	---	---
m = 2	. . . . .	0.7600000000	---	---	---	---
m = 3	. . . . .	0.5000000000	0.3333333333	---	---	---
m = 6	. . . . .	0.0287202536	0.0287202536	---	0.0029677419	0.0062500000
m = 7	. . . . .	---	0.0002728424	---	---	---
m = 8	. . . . .	---	0.0015394056	---	---	---
m = 9	. . . . .	---	0.0005485568	---	---	---
m = 4	. . . . .	0.6666666667	0.1666666667	---	---	---
m = 5	. . . . .	8.0000000000	0.3333333333	---	---	---

<sup>a</sup>Periods of time are in units of hours per production run for phases one through five, and in units of hours per hundredweight for phases six through nine.



## APPENDIX D

Elapsed Time of Variable Production Run Phases  
Expressed as a Function of Output ( $T_{ij}$ )

The technique used for calculation of the " $T_{ij}$ " values will be described in this appendix. These values are used in the variable phases descriptions of Appendix C, and in the variable phase cost element requirement calculations of Appendix H.

A specific processing rate has been established in this study for the model plant equipment. A definite period of time will therefore be required for processing a specified quantity of final product. The costs of the cost elements required during the processing period will be the source of the processing costs for that quantity. The sum of all cost element costs for the processing period will be the total processing cost which can be restated as an average processing cost per unit of product. This relationship can be expressed by the following notation:

$$\frac{\text{Average processing cost}}{\text{Unit product}} = \frac{\text{Cost element price}}{\text{Unit cost element}} \times \frac{\text{Cost element requirement}}{\text{Processing hour}} \times \frac{\text{Processing hours}}{\text{Unit product}} \quad (1)$$

It will be the purpose of this appendix to calculate the values required for the "processing hours per unit product" term of notation (1). These values will be denoted as " $T_{ij}$ " and will state the quantity of elapsed processing time required for the  $i^{\text{th}}$  maintenance phase and the  $j^{\text{th}}$  production week per hundredweight unit of product.

The two-year average processing rate for the dryer was calculated for Table 46 by means of the following relationship:

$$\frac{\text{Total product}}{\text{Total hours}} = \frac{\text{Average product}}{\text{Hour unit}} = \frac{3,481.8634 \text{ lbs. powder}}{\text{Hour}} \quad (2)$$

This same data can be restated in the inverse relationship which will provide the value required "processing hours per unit product" term of notation (1) for the "processing" phases of stages I, II, and III. The inverse relationship produces the following value:

$$\frac{\text{Total hours}}{\text{Total product}} = \frac{\text{Average hours}}{\text{Unit product}} = \frac{0.0287202536 \text{ hour}}{\text{Cwt. product}} \quad (3)$$

The ratio obtained in notation (3) must be adjusted somewhat further for use with the "maintenance" phases of stages II and III since those phases do not run continuously during processing. The adjustment is made by reference to the " $R_{ij}$ " values calculated in Appendix G. The necessary adjustment can be indicated by the following notation:

$$T_{ij} = \left( \frac{0.0287202536 \text{ hr.}}{\text{Cwt. product}} \right) (R_{ij}) \quad (4)$$

where:

$T_{ij}$  = as defined above, and

$R_{ij}$  = ratio of time assigned to the  $i^{\text{th}}$  maintenance phase and the  $j^{\text{th}}$  weekly definition to total processing time (Table 51).

" $T_{ij}$ " values for the processing phases of stages V and VI were calculated directly from observations of the total time required to load given quantities of powder. The calculation used the same form as notation (3) above. " $T_{ij}$ " values will be calculated for each of the variable

phases in the remainder of this appendix and the values will be summarized in tabular form at the end.

### Stage I: Evaporating

The evaporator has been assumed to be directly interconnected to the dryer during the periods of processing under consideration in this study. The inverse calculation of the dryer processing rate from above is therefore also applicable to the evaporating stage.

Operating phase.--The "T" values for the operating phase of stage I were denoted as " $T_{1j}$ ." The periods of stage I operating phase time required per hundredweight of powder are as follows:

$$\text{5-day weeks: } T_{11} = 0.0287202536 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{12} = 0.0287202536 \text{ hr./cwt.}$$

### Stage II: Drying

The basic relationship (3) developed above for the dryer was used in some form for all phases of this stage.

Operating phase.--The "T" values for the operating phase of stage II were denoted as " $T_{1j}$ ." Basic relationship (3) was used directly for this phase. Periods of stage II operating phase time required per hundredweight powder are as follows:

$$\text{5-day weeks: } T_{11} = 0.0287202536 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{12} = 0.0287202536 \text{ hr./cwt.}$$

Shutting-down for downtime phase.--The "T" values for this phase of stage II were denoted as " $T_{2j}$ ." Relationship (4) was used for this phase with  $R_{21} = 0.0045$  and  $R_{22} = 0.0095$ . Periods of this phase required per hundredweight powder are as follows:



5-day weeks:  $T_{21} = 0.0001292411 \text{ hr./cwt.}$

6-day weeks:  $T_{22} = 0.0002728428 \text{ hr./cwt.}$

Downtime for maintenance phase.--The "T" values for this phase of stage II were denoted as " $T_{3j}$ ." Relationship (4) was used for this phase with  $R_{31} = 0.0232$  and  $R_{32} = 0.0536$ . Periods of this phase required per hundredweight of powder are as follows:

5-day weeks:  $T_{31} = 0.0006663099 \text{ hr./cwt.}$

6-day weeks:  $T_{32} = 0.0015394056 \text{ hr./cwt.}$

Warm-up after downtime phase.--The "T" values for this phase of stage II were denoted as " $T_{4j}$ ." Relationship (4) was used for this phase with  $R_{41} = 0.0089$  and  $R_{42} = 0.0191$ . Periods of this phase required per hundredweight of powder are as follows:

5-day weeks:  $T_{41} = 0.0002556103 \text{ hr./cwt.}$

6-day weeks:  $T_{42} = 0.0005485568 \text{ hr./cwt.}$

### Stage III: Bagging

The above basic relationship (3) developed for the dryer was used in some form for all phases of this stage.

Operating phase.--The "T" values for the operating phases of stage III were denoted as " $T_{1j}$ ." Basic relationship (3) was used directly for this phase. Periods of this phase required per hundredweight of powder are as follows:

5-day weeks:  $T_{11} = 0.0287202536 \text{ hr./cwt.}$

6-day weeks:  $T_{12} = 0.0287202536 \text{ hr./cwt.}$

Shutting-down for dryer maintenance phase.--The "T" values for this phase of stage III were denoted as " $T_{2j}$ ." Relationship (4) was used for this phase with  $R_{21} = 0.0045$  and  $R_{22} = 0.0095$ . Periods of this phase required per hundredweight of powder are as follows:

$$\text{5-day weeks: } T_{21} = 0.0001292411 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{22} = 0.0002728424 \text{ hr./cwt.}$$

Downtime for dryer maintenance phase.--The "T" values for this phase of stage III were denoted as " $T_{3j}$ ." Relationship (4) was used for this phase with  $R_{31} = 0.0232$  and  $R_{32} = 0.0536$ . Periods of this phase required per hundredweight of powder are as follows:

$$\text{5-day weeks: } T_{31} = 0.0006663099 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{32} = 0.0015394056 \text{ hr./cwt.}$$

Warm-up after dryer downtime phase.--The "T" values for this phase of stage III were denoted as " $T_{4j}$ ." Relationship (4) was used for this phase with  $R_{41} = 0.0089$  and  $R_{42} = 0.0191$ . Periods of this phase required per hundredweight of powder are as follows:

$$\text{5-day weeks: } T_{41} = 0.0002556103 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{42} = 0.0005485568 \text{ hr./cwt.}$$

#### Stage IV: Storage

Operating phase.--No " $T_{1j}$ " values were required for this phase.

#### Stage V: Truck loading

Operating phase.--The "T" values for the operating phase of stage V were developed directly from observations made during the study and not

obtained from plant records. The "T" values for this stage were denoted as " $T_{1j}$ " and were calculated from the following relationship:

$$\begin{aligned}\frac{\text{Total phase hours}}{\text{Total powder loaded}} &= \frac{0.9167 \text{ hrs.}}{310 \text{ cwt.}} \\ &= 0.0029570968 \text{ hr./cwt.} \quad (5)\end{aligned}$$

Periods of this phase required per hundredweight of powder are as follows:

$$\text{5-day weeks: } T_{11} = 0.0029570968 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{12} = 0.0029570968 \text{ hr./cwt.}$$

#### Stage VI: Railroad car loading

Operating phase.--The "T" values for this phase were denoted as " $T_{1j}$ " and were developed in the same manner as for (5) of stage V.

$$\begin{aligned}\frac{\text{Total phase hours}}{\text{Total powder loaded}} &= \frac{5.0000 \text{ hrs.}}{800 \text{ cwt.}} \\ &= 0.0062500000 \text{ hr./cwt.} \quad (6)\end{aligned}$$

Periods of this phase required per hundredweight of powder are as follows:

$$\text{5-day weeks: } T_{11} = 0.0062500000 \text{ hr./cwt.}$$

$$\text{6-day weeks: } T_{12} = 0.0062500000 \text{ hr./cwt.}$$



TABLE 41.--Summary of "T<sub>ij</sub>" values expressing hours required of each variable phase per hundredweight of powder for model plant production

Phases	5-day weeks (j = 1)					
	Stage I Evaporating	Stage II Drying	Stage III Bagging	Stage IV Storage	Stage V Truck ldg.	Stage VI RR car ldg.
Operating (i = 1)	0.0287202536	0.0287202536	0.0287202536	--	0.0029570968	0.0062500000
Shutting-down for maintenance (i = 2)	--	0.0001292411	0.0001292411	--	--	--
Downtime for maintenance (i = 3)	--	0.0006663099	0.0006663099	--	--	--
Warm-up after downtime (i = 4)	--	0.0002556103	0.0002556103	--	--	--
6-day weeks (j = 2)						
Operating (i = 1)	0.0287202536	0.0287202536	0.0287202536	--	0.0029570968	0.0062500000
Shutting-down for maintenance (i = 2)	--	0.0002728424	0.0002728424	--	--	--
Downtime for maintenance (i = 3)	--	0.0015394056	0.0015394056	--	--	--
Warm-up after downtime (i = 4)	--	0.0005485568	0.0005485568	--	--	--

## APPENDIX E

## Processing Rates, Solids Losses, and Skim/Powder Ratio

Record sheets were kept by the case study plant for operation of both the evaporator and the dryer. Records for the evaporator were filled out by the operator during processing. Items that were recorded included periods of operation, quantities of skim metered into the evaporator, Baume hydrometer readings of the product leaving the evaporator, and other entries pertaining to operation of the evaporator (temperatures, etc.). Summarization of quantities incoming quantities of skim milk from these evaporator record sheets, by months, for a two-year period is presented in Table 42. Also included in this table are average solids contents of whole milk incoming to the plant and the total solids content of the skim going to the evaporator during this period.

Recording of data for the dryer operation was made directly on the circular recording charts by the operator during processing. Items recorded were total number of bags filled, type of powder produced and results of powder moisture tests. Summarization of total powder production and average moisture content entries from these record sheets, by months, for a two-year period is presented in Table 43. Also included is the total moisture content of the powder as obtained from the average moisture content record.

Processing rates

Average processing rates for the evaporator and dryer can be derived from data in Tables 42 and 43. These rates are based upon an

TABLE 42.--Evaporator production record data obtained from case study plant records

Month	Operations (hrs.:min.)	Skim (lbs.)	Solids	
			Percentage	Lbs.
1962				
July	251 : 51	9,753,877	8.840	862,243
August	208 : 50	8,168,242	8.850	722,889
September	148 : 56	5,962,000	8.830	526,445
October	153 : 54	6,126,445	8.850	542,190
November	160 : 33	6,395,113	8.950	572,362
December	174 : 56	6,968,508	9.014	628,141
1963				
January	148 : 16	5,857,387	8.999	527,106
February	138 : 37	5,343,525	8.921	476,696
March	145 : 18	5,827,657	8.986	523,673
April	190 : 45	7,574,137	8.933	676,559
May	247 : 44	9,870,817	8.967	885,116
June	232 : 59	9,350,534	8.907	832,859
July	213 : 03	8,557,954	8.931	764,328
August	199 : 38	7,937,780	8.946	710,146
September	153 : 55	6,137,882	8.891	545,719
October	154 : 30	6,212,652	8.886	552,056
November	183 : 38	7,280,330	8.878	646,377
December	197 : 36	7,877,614	8.908	701,703
1964				
January	194 : 38	6,683,887	10.269	686,382
February	206 : 20	8,052,437	8.929	718,993
March	231 : 09	8,912,088	8.978	800,127
April	260 : 04	10,003,832	9.010	901,345
May	357 : 20	13,496,367	8.962	1,209,544
June	342 : 11	13,062,787	8.964	1,170,948
Totals	4,896 : 41	191,413,852	8.977	17,183,947



TABLE 43.--Dryer production record data obtained from case study plant records

Month	Operation period		Powder (lbs.)	Moisture	
	Hours	Days		Percentage	Lbs.
1962					
July	184:10	25	654,150	3.280	21,456
August	154:10	22	524,950	3.380	17,743
September	104:00	18	378,250	3.500	13,239
October	113:20	21	414,330	3.560	14,750
November	128:30	22	466,605	3.560	16,611
December	146:45	22	540,200	3.462	18,702
1963					
January	110:00	19	396,769	3.593	14,256
February	99:15	19	354,400	3.598	12,751
March	105:00	19	360,712	3.569	12,874
April	142:00	23	492,025	3.556	17,496
May	196:50	27	676,600	3.285	22,226
June	188:30	25	659,140	3.353	23,101
July	200:45	24	695,575	3.415	23,754
August	153:00	26	527,450	3.585	18,909
September	98:00	19	331,588	3.639	12,066
October	104:00	19	365,850	3.565	13,043
November	143:30	23	519,780	3.784	19,668
December	159:15	21	564,950	3.733	21,090
1964					
January	150:30	23	535,200	3.709	19,851
February	207:30	25	714,750	3.652	26,103
March	173:00	23	607,110	3.739	22,697
April	249:45	26	853,150	3.335	28,453
May	386:30	26	1,283,000	3.560	45,675
June	318:00	26	1,067,500	3.452	36,850
Totals	4,016:15	543	13,984,034	3.526	493,364

accumulation of records for a two-year period and include operation under several different sets of operating conditions as will be indicated. In particular dryer records cover some periods in which the dryer and evaporator were not operating interconnectedly.

Evaporator input processing rates.--The evaporator was designed to operate at full capacity during all processing periods. The definition to be used here for "hours of operation" is the same as the processing period defined for the "operating phase" in Appendix C. Average processing rates for the evaporator are calculated from case study plant record data in Table 42 and the following general relationship:

$$\frac{\text{Average input}}{\text{Unit of time}} = \frac{\text{Total input}}{\text{Total units of time}} \quad (1)$$

Processing rates in terms of skim milk and milk solids are summarized in Table 44. These processing rates are a two-year weighted average of all processing. As indicated in the technology section of Part III, the evaporator was used for processing more than one type of condensed milk product during this period. It is possible that there were variations in processing rates associated with these various products that were not discernible from the records.

TABLE 44.--Two-year average evaporator processing rates obtained from case study plant records

Processing period	Skim milk	Solids
Pounds		
Hourly . . . . .	39,090.6171	3,509.3129
Monthly . . . . .	7,975,577.1667	715,998.7917
Annually . . . . .	95,706,926.0000	8,591,973.5000

Average processing rates also average out variations in production due to factors other than the type of product. Such factors include atmospheric conditions, steam pressures and temperatures as well as variations in operator techniques. No attempt was made to identify any of these factors or their effects.

In order to compare aggregate periods of evaporator and dryer operation, an average processing period was developed from data in Table 42. The general relationship used for these values was as follows:

$$\frac{\text{Average hours operation}}{\text{Unit of time}} = \frac{\text{Total hours operation}}{\text{Total units of time}} \quad (2)$$

Average monthly and annual periods of evaporator operation are presented in Table 45.

TABLE 45.--Two-year average periods of evaporator operation obtained from case study plant records

Time period	Period of operation
	Hours
Monthly	204.0279
Annually	2,448.3350

Dryer output processing rates.--During the major portion of operations in the case study plant the dryer in the drying stage was directly connected to the evaporator in the evaporating stage. Under conditions in which the two stages are directly connected the input processing rate of the dryer will be essentially identical to the output processing rate of the evaporator. Potential loss of solids during transfer operations was thought to be negligible.



During periods in which the drying stage is processing condensed milk from a storage vat, however, it is possible to vary the processing rate of the dryer. Processing rates for the dryer from plant records are an average of both types of product flow for the two-year period covered in Table 43. Although no analysis of the effects of these two types of operation upon the average processing rate was attempted, an illustration of the quantities of solids moving into and out of the case study plant is presented in Figure 10 of the "solids losses" section.

The average processing rates in terms of outputs can be derived for hourly, daily, and monthly time periods. Data from Table 43 is used and each average is computed using the following general statement:

$$\frac{\text{Average output}}{\text{Unit of time}} = \frac{\text{Total output}}{\text{Total units of time}} \quad (3)$$

Table 46 summarizes these processing rates and reflects operation of the dryer both during periods when the evaporator and dryer were directly connected and when the dryer was connected to a storage vat.

TABLE 46.--Two-year average dryer processing rates obtained from case study plant records

Processing period	Powder	Solids
	Pounds	
Hourly . . . . .	3,481.8634	3,359.0215
Daily . . . . .	25,753.2854	24,844.6961
Monthly . . . . .	582,668.0000	562,111.0000
Yearly . . . . .	6,992,017.0000	6,745,335.0000

Data in Table 43 can also be used to develop average lengths of processing periods for both daily and monthly time periods. Table 47 summarizes these values.

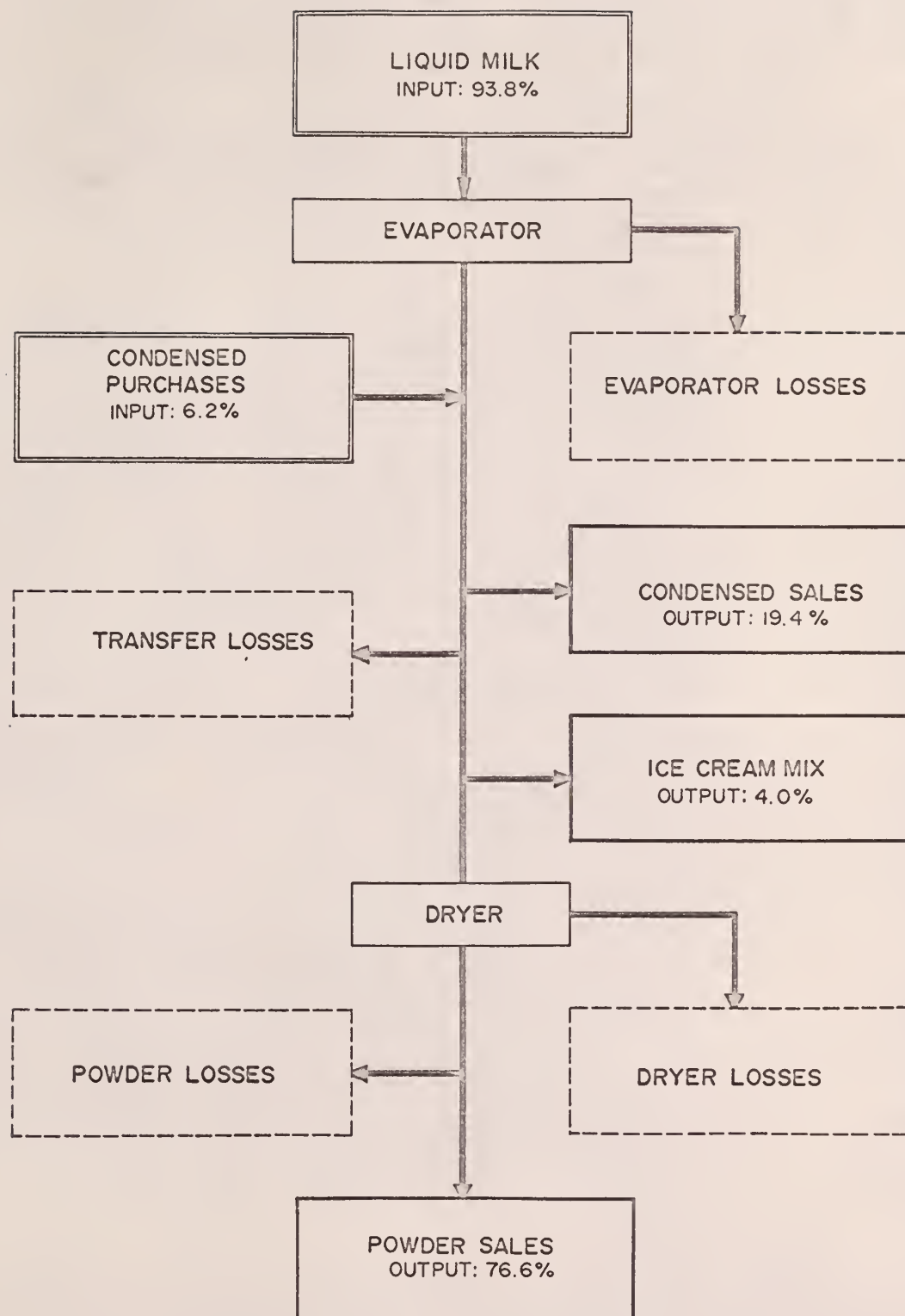


Fig. 10.--Illustration of inputs and outputs of milk solids, and locations of potential solids losses in the model plant.

TABLE 47.--Two-year average periods  
of dryer operation obtained from case  
study plant records

Type of processing period	Duration
	Hours
Daily . . . . .	7.3964
Monthly . . . . .	167.3500
Yearly . . . . .	2008.1250

An analysis of the solids losses during processing will be presented in the next section. Using the solids loss figures that will be developed and some assumptions as to the nature of these losses it will be possible to construct a "synthetic" processing rate for the dryer in Appendix F. This will represent an attempt to calculate a rate that could reasonably have been expected during processing in which the evaporator and dryer were directly connected. It will provide an evaluation of the degree to which the above average processing rate may have been affected by the variety of processing product flow combinations that were possible during the period covered by the data.

Solids losses.--A rough accounting for milk solids can be made by reference to case study plant records. Inputs and outputs of solids and locations of possible losses were indicated diagrammatically in Figure 10. Measured volumes of solids contained in the incoming skim to the evaporator are given in Table 42. Measured volumes of solids contained in powder produced by the dryer are given in Table 43. Reference to Table 48 is made for the remaining measured volumes of condensed solids purchased, sold, or transferred to other departments within the plant.



TABLE 48.--Two-year record of solids transfers into and out of the powdered milk process as obtained from case study plant records

Month	Condensed solids purchased	Solids sold as condensed	Solids used in ice cream mix
1962			
		Pounds	
July	--	160,377	23,211
August	--	168,952	25,897
September	--	125,565	19,018
October	--	118,521	17,329
November	--	96,669	15,312
December	--	63,931	17,388
1963			
January	--	118,377	17,077
February	--	104,619	15,598
March	--	121,724	27,278
April	--	133,498	36,718
May	--	156,303	34,463
June	36,087	151,802	28,223
July	176,457	178,346	45,303
August	46,857	164,385	42,505
September	--	122,067	34,998
October	--	140,409	34,893
November	--	116,638	28,073
December	14,852	133,777	27,094
1964			
January	31,410	168,465	28,562
February	184,246	155,021	25,817
March	15,270	162,505	42,364
April	174,160	174,034	35,133
May	292,353	160,738	40,265
June	171,246	215,993	34,788
Total	1,142,938	3,412,716	697,307

For the two-year period covered by these records, total volume of solids introduced into the evaporating-drying process can be obtained from Tables 42 and 48 as follows:

$$\begin{aligned}
 \text{Total solids input} &= \text{Total skim solids input} + \text{Total condensed solids purchased} \\
 &= 17,183,947 \text{ lbs.} + 1,142,938 \text{ lbs.} \\
 &= 18,326,885 \text{ lbs.} \quad . \quad (4)
 \end{aligned}$$

Total volume of solids that can be accounted for leaving the evaporating-drying process can be obtained from Tables 43 and 48 as follows:

$$\begin{aligned}
 \text{Total solids output} &= \text{Total solids sold as condensed} + \text{Total ice cream mix solids} + \text{Total powder solids} \\
 &= 3,412,716 \text{ lbs.} + 697,307 \text{ lbs.} \\
 &+ 13,490,670 \text{ lbs.} = 17,600,693 \text{ lbs.} \quad . \quad (5)
 \end{aligned}$$

Total volume of solids lost to the various operations as noted in Figure 10 can be taken as the difference between these two total volumes for the two-year period:

$$\begin{aligned}
 \text{Total solids lost} &= \text{Total solids input} - \text{Total solids output} \\
 &= 18,326,885 \text{ lbs.} - 17,600,693 \text{ lbs.} \\
 &= 726,192 \text{ lbs.} \quad . \quad (6)
 \end{aligned}$$

Total solids loss can be expressed as a percentage of the total solids introduced into the evaporating-drying process.

$$\begin{aligned}
 \text{Percentage solids loss} &= \frac{\text{Total solids lost}}{\text{Total solids input}} = \frac{726,192 \text{ lbs.}}{18,326,885 \text{ lbs.}} \\
 &= 3.9624 \text{ percent} \quad . \quad (7)
 \end{aligned}$$

This solids loss figure can strictly be considered valid only when the proportion of solids inputs from all sources and solids outputs to all uses are present in the same proportion as was the case for the

period from which the case study plant records were drawn. During the two-year period covered by records, inputs to the process were divided approximately 93.8 percent skim solids to the evaporator and 6.2 percent outside purchases of condensed solids.

It is probable that there would have been certain transfer losses associated with purchase of outside condensed solids that would not otherwise have been encountered when the dryer was operating directly connected to the evaporator. As an offsetting factor, there would have been solids losses due to operation of the evaporator that would not have been encountered when outside purchases were made. The net effect of these offsetting tendencies was not known.

On the output side, total output for the two-year period was divided three ways with approximately 19.4 percent solids sold as condensed, 4.0 percent solids transferred to ice cream mix, and 76.6 percent solids sold as powder. Here again, transfer losses of the condensed solids sold and condensed solids transferred to ice cream mix would probably have been offset to some extent by the losses that would otherwise have occurred in the dryer. The net effect here, as for the previously noted input case, could not be determined.

The overall net effect considering both the combination of inputs and outputs has not been evaluated either. A conversion ratio of solids input to solids output can be stated but it is valid, in a strict sense, only for the process in its entirety and in the above processing combination of outside purchases and sales of condensed product. Calculation of a solids conversion ratio from data in Tables 42, 43, and 48 is as follows:

$$\begin{aligned}
 \text{Input/output} &= \frac{\text{Total solids output}}{\text{Total solids input}} \\
 \text{Solids conversion ratio} &= \frac{17,598,983 \text{ lbs.}}{18,326,885 \text{ lbs.}} = \frac{0.960282}{1.0} \quad (8)
 \end{aligned}$$



This indicates that a given volume of solids introduced into the process in the proportions indicated above, and distributed among the outputs in the proportions as stated, can be expected to yield a volume of solids only 96.0282 percent as great. This is equivalent to a solids loss of 3.9718 percent of the original solids or an input/output solids ratio of 1.041361:1.0.

Skim-to-powder conversion ratio.--Cost calculations for this study, presented in Part V, are stated in terms of output units. Occasion may arise to convert these data to units of input for comparison purposes. This would require development of a conversion ratio.

The relationship between incoming milk and output of product can be developed from the average processing rates for the evaporator and the dryer. This conversion ratio carries the same limitations and assumptions as were noted above when stating the dryer processing rate.

$$\begin{aligned} \frac{\text{Lbs. skim}}{\text{Lb. powder}} &= \frac{\text{Lbs. skim/hour}}{\text{Lbs. powder/hour}} = \frac{39,090.6171 \text{ lbs.}}{3,481.8634 \text{ lbs.}} \\ &= 11.22692438 \end{aligned} \quad (9)$$

It will require 11.22692438 pounds of skim milk to produce one pound of powder under the processing conditions assumed for this study.

It may occasionally be useful to have the relationship between skim milk and powder expressed in its reciprocal form:

$$\begin{aligned} \frac{\text{Lbs. powder}}{\text{Lb. skim}} &= \frac{\text{Lbs. powder/hour}}{\text{Lbs. skim/hour}} = \frac{3,481.8634 \text{ lbs.}}{39,090.6171 \text{ lbs.}} \\ &= 0.0890715895 \end{aligned} \quad (10)$$

A total of 8.90715895 pounds of milk powder can be expected from one hundred pounds of skim milk introduced into the milk drying process of the model plant.

## APPENDIX F

## Synthetic Dryer Processing Rate

The dryer processing rate developed in Appendix E was a weighted average obtained from operating records covering many varying rates of processing during the two-year period. It is possible that the average rate is not the same as would have been the case if all drying had occurred with the dryer connected directly to the evaporator. Operation of the dryer at either appreciably higher or lower rates during periods in which condensed milk is pumped to the dryer from a vat would have affected the resulting average. It would be useful to know the "connected" processing rate of the dryer but sufficient data was not available.

It is possible, however, to calculate a "synthetic processing rate" for the dryer from the values previously developed for solids losses and solids content of skim and powder. This dryer processing rate is consistent with synchronous operation of the evaporator and dryer under assumptions stated. Figure 11 illustrates the calculations that were used in developing this concept.

The values from Appendix E which are taken as given for developing this "synthetic rate" are as follow:

$$\frac{\text{Lbs. skim}}{\text{Hour}} = 39,090.6171 \quad , \quad (1)$$

$$\frac{\text{Lbs. solids}}{\text{Lb. skim}} = 0.089774 \quad , \quad (2)$$

$$\frac{\text{Lbs. solids lost}}{\text{Lb. solids}} = 0.039718 \quad , \quad (3)$$

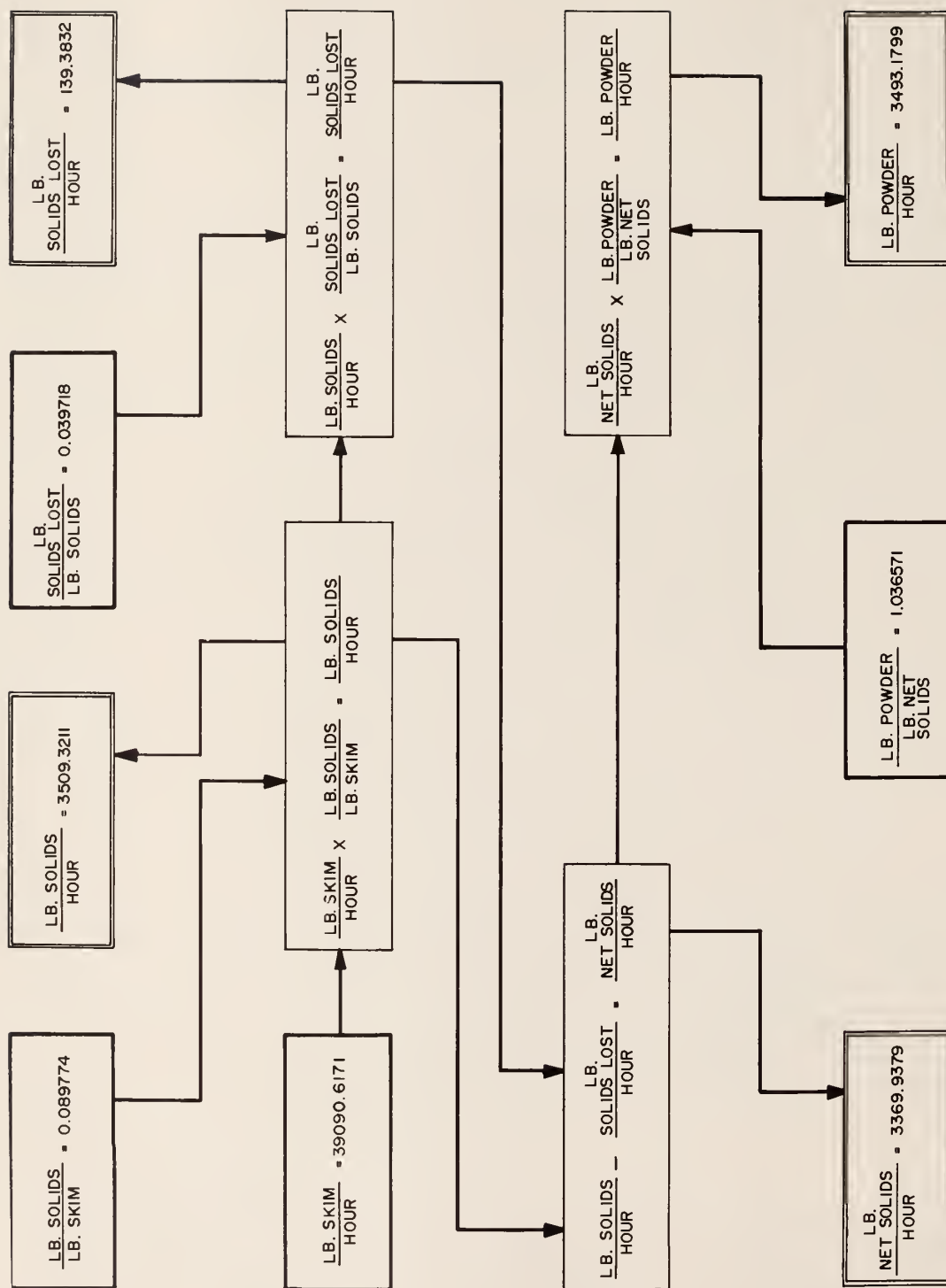


Fig. 11.--Flow diagram illustration of the "synthetic dryer processing rate" calculation procedures.



$$\frac{\text{Lbs. powder}}{\text{Lb. net solids}} = \frac{1.0}{0.964720} = 1.036470 \quad (4)$$

It is assumed that the evaporator (pan) and dryer were operating in direct connection and that total loss of solids are the same percentage as was developed above from data gathered for all types of condensed operations.

It is felt that the assumption just made for solids losses is not particularly unreasonable in light of the relatively small quantities of condensed milk purchased (6.2 percent), sold (19.4 percent), and transferred (4.0 percent). Final comparison of the synthetic rate to be developed here on this assumption and the average rate from the records will show a very close correlation.

The "skim per hour" and the "solids lost per pound of solids" values were previously developed in Appendix E. The "solids per pound of skim" value can be obtained by reference to Table 42.

$$\begin{aligned} \frac{\text{Lbs. solids}}{\text{Lb. skim}} &= \frac{\text{Total skim solids}}{\text{Total pounds skim}} \\ &= \frac{17,183,947 \text{ lbs.}}{191,413,852 \text{ lbs.}} = 0.089774 \quad (5) \end{aligned}$$

The "powder per pound of net solids (after losses)" value can be obtained from Table 43, by using a conversion of the total moisture figures to total solids (lbs. powder - lbs. moisture = lbs. solids).

$$\begin{aligned} \frac{\text{Lbs. powder}}{\text{Lb. net solids}} &= \frac{\text{Total powder}}{\text{Total powder} - \text{Total moisture}} \\ &= \frac{13,984,034 \text{ lbs.}}{13,984,034 \text{ lbs.} - 493,364 \text{ lbs.}} \\ &= \frac{13,984,034 \text{ lbs.}}{13,490,670 \text{ lbs.}} = 1.036571 \quad (6) \end{aligned}$$

After determining these values, which will be assumed to be appropriate to this use and therefore taken as given, the calculation of the

synthetic rate can proceed as summarized in Figure 11.

$$\begin{aligned}
 \frac{\text{Lbs. solids}}{\text{Hour (pan)}} &= \left( \frac{\text{Lbs. skim}}{\text{Hour}} \right) \left( \frac{\text{Lbs. solids}}{\text{Lb. skim}} \right) \\
 &= \left( 39,090.6171 \text{ lbs.} \right) \left( 0.089774 \right) \\
 &= 3,509.3211 \text{ lbs.}
 \end{aligned} \tag{7}$$

This is the average pounds of solids per hour contained in the skim entering into the evaporator (pan). From this initial quantity will be lost 3.9718 percent by weight to all possible losses in the process.<sup>1</sup>

$$\begin{aligned}
 \frac{\text{Lbs. solids lost}}{\text{Hour}} &= \left( \frac{\text{Lbs. solids}}{\text{Hour (pan)}} \right) \left( \frac{\text{Lbs. solids lost}}{\text{Lb. solids}} \right) \\
 &= \left( 3,509.3211 \text{ lbs.} \right) \left( 0.039718 \right) \\
 &= 139.3832 \text{ lbs.}
 \end{aligned} \tag{8}$$

Subtracting this hourly solids loss from the hourly solids figure for the evaporator will yield the hourly net solids that would be bagged as powder.

$$\begin{aligned}
 \frac{\text{Lbs. net solids}}{\text{Hour}} &= \frac{\text{Lbs. solids}}{\text{Hour}} - \frac{\text{Lbs. solids lost}}{\text{Hour}} \\
 &= 3,509.3211 \text{ lbs.} - 139.3832 \text{ lbs.} \\
 &= 3,369.9379 \text{ lbs.}
 \end{aligned} \tag{9}$$

The final "synthetic" hourly processing rate for the dryer is obtained when this net solids figure is adjusted for the solids content (or conversely the moisture content) of the powder.

$$\begin{aligned}
 \frac{\text{Lbs. powder}}{\text{Hour}} &= \left( \frac{\text{Lbs. net solids}}{\text{Hour}} \right) \left( \frac{\text{Lbs. powder}}{\text{Lb. net solids}} \right) \\
 &= \left( 3,369.9379 \text{ lbs.} \right) \left( 1.036471 \right) \\
 &= 3,493.1799 \text{ lbs.}
 \end{aligned} \tag{10}$$

---

<sup>1</sup>See "solids loss" calculations of Appendix E.

As recapitulation, given first that the evaporator is running at the rate stated, second that the solids contents of skim and powder are as stated, and third that total losses of solids are as stated, it can be hypothesized that the dryer will produce 3,493.1799 lbs. powder hourly when connected directly to the evaporator. This is a "synthetic" processing rate for the dryer.

It is interesting to compare this synthetic processing rate with the weighted average rate obtained from the plant records.

$$\begin{aligned}
 \frac{\text{"Synthetic" rate} - \text{Plant average}}{\text{Plant average}} &= \frac{3,493.1799 \text{ lbs.} - 3,481.8634 \text{ lbs.}}{3,481.8634 \text{ lbs.}} \\
 &= \frac{11.3165 \text{ lbs.}}{3,481.8634 \text{ lbs.}} \\
 &= 0.003250 \qquad (11)
 \end{aligned}$$

The "synthetic" rate, with its attendant assumptions, is only 0.325 percent larger than the two-year plant average rate. It would appear that the assumptions used were reasonable for the operation of this plant.

This synthetic rate for the dryer was not used for this study. It was informative as a check to determine if the plant average rate was reasonably close to that which could be expected when the evaporator was directly connected to the dryer. However, since the discrepancy was slight, it was elected to use the plant average processing rate obtained from the data in Table 43.

Skim-to-powder conversion ratio.--The synthetic processing rate just calculated for the dryer can be compared to the processing rate of the evaporator. This will yield an overall skim-to-powder synthetic conversion ratio that could be expected under the assumed processing conditions.



$$\frac{\text{Lbs. skim}}{\text{Lb. powder}} = \frac{\text{Lbs. skim/hour}}{\text{Lbs. powder/hour}} = \frac{39,090.6171 \text{ lbs.}}{3,493.1799 \text{ lbs.}}$$

$$= 11.190554 \quad (12)$$

It would require 11.190554 pounds of skim to produce one pound of powder under the processing conditions assumed.

## APPENDIX G

## Analysis of Case Study Plant Dryer Downtime Data

During interviews with the plant personnel it was learned that there had been a degree of maintenance difficulty with the dryer during processing. These interruptions were the result of sprayer nozzles becoming plugged or from damp powder collecting on the inside top of the drying chamber. This eventually led to either flaking of the powder in chunks large enough to block an airlock, or it occasionally became hot enough to scorch.

Plant management believed that the best defense against such stoppages was a rigorous cleanup program. Whenever the work load permitted time for preventive maintenance, it was customary to supplement the regular nightly cleanup of the dryer with a half day preventive maintenance cleanup at midweek.

This practice led to the identification of two different types of weekly operating periods for the analysis of this study. The first of these can be referred to as a "five-day processing week." This type of operating period occurred when the work load was light enough to permit a midweek preventive maintenance cleanup on successive weeks. Since the greatest part, or all, of the cleanup day was lost for processing and processing was not done on Sunday, this operating period was referred to as a "five-day processing week."

The second type of period was referred to as a "six-day processing week." This type of operating period occurred when the work load was

sufficient to preclude a midweek cleanup. For purposes of definition, it was considered to begin on the day that a midweek cleanup would normally have occurred.

Recording charts used for the dryer operation were reviewed in order to determine the overall relationship that time lost to stoppages of the nature described bore to actual processing time. The dryer recording charts were of the circular, twenty-four hour time-span type and were available for individual study for this tabulation.

Consecutive charts were initially identified as falling into either "five-day" or "six-day" processing weeks as defined above. Each individual chart within these groups was examined and it was decided that daily production runs could be divided into roughly three different periods. These three periods were as follows: an operating period, a period of downtime lasting from the termination of processing until the start of the warm-up, and a warm-up period lasting until resumption of processing. Tabulation of the dryer records on the basis of these three categories is presented in Table 49.

Upon the basis of this analysis of case study plant records spanning eighteen months of operations a relationship was established between aggregate periods of downtime and processing time, and also between aggregate periods of warm-up and processing time.

Ratios of aggregate downtime to processing time for the two types of processing weeks were as follows:

$$\frac{\text{Total 5-day downtime}}{\text{Total processing time}} = \frac{19.33 \text{ hrs.}}{699.58 \text{ hrs.}} = 0.0276 \quad (1)$$

$$\frac{\text{Total 6-day downtime}}{\text{Total processing time}} = \frac{60.22 \text{ hrs.}}{952.88 \text{ hrs.}} = 0.0632 \quad (2)$$



TABLE 49.---Summary of case study plant down-time observations for an eighteen month period, classified by five-day and six-day processing week definitions

5-day weeks				6-day weeks			
Week	Processing time	Down-time	Warm-up after D-T	Week	Processing time	Down-time	Warm-up after D-T
9/11-17/63	17.83	0	0	8/7-13/63	29.75	2.08	0.33
10/3-9/62	23.50	1.08	0.42	5/1-7/63	32.25	2.67	1.00
11/7-13/62	23.58	0.83	0.08	5/8-14/63	33.83	2.42	0.67
9/25-10/1/63	24.00	0.33	0.08	5/21-27/63	34.83	4.58	0.92
2/13-19/63	24.33	3.00	0.08	5/15-21/63	41.33	0.50	0.25
1/23-29/63	25.00	2.33	0.58	12/26-1/1-63	42.33	0.75	0.08
11/28-12/4/63	25.75	0	0	6/20-26/62	44.08	1.83	3.08
3/27-4/2/63	26.00	0	0	8/28-9/3/63	45.58	2.33	0.58
1/30-2/5/63	26.50	0.50	0.08	11/26-12/3/63	46.33	0	0
4/3-9/63	26.75	2.50	0.58	6/5-11/63	46.75	2.25	1.00
11/14-20/62	27.08	0.17	0.08	1/1-7/64	46.83	4.33	1.00
2/20-26/63	28.42	1.67	0.67	5/22-28/63	48.33	2.42	0.33
12/5-11/62	28.92	1.25	0.75	5/29-6/4/63	54.08	0.83	0.42
11/6-12/63	29.58	0	0	12/25-31/63	56.33	0.58	0.17
9/18-24/63	29.67	1.00	0.17	6/6-12/62	60.25	7.33	1.17
10/31-11/6/62	30.58	1.08	1.67	5/23-29/62	63.33	11.32	1.58
12/19-25/62	30.92	0.17	0.17	6/13-19/62	69.17	6.32	4.92
12/12-18/62	31.58	1.17	0.42	5/30-6/5/62	76.17	0	0
10/24-30/62	33.92	0	0	5/16-22/62	81.33	7.67	0.67
11/20-26/63	33.92	0.58	0.08	Total	952.88	60.22	18.17
12/19-24/63	34.67	1.67	0.33				
4/10-16/63	34.75	0	0				
4/17-23/63	36.00	0	0				
7/25-31/62	46.33	0	0				
Total	699.58	19.33	6.24				

The ratio for six-day weeks is more than twice as large as for five-day weeks. It appears that some factor present in the six-day week operations is aggravating the causes of stoppage during processing.

The six-day production weeks occurred during periods when output of the plant was high because processing was being continued for longer hours. Since the aggregate amount of recorded downtime was greater for the six-day weeks than for the five-day weeks, it was thought possible that there might be a relationship of some nature between hours of recorded downtime and hours of processing during a week. In order to analyze this possibility, it was decided to test the null hypothesis that there was no significant relationship between these two variables.

#### Linear regression analysis of downtime

Least-squares trend lines for the linear regression of downtime upon processing time were calculated for both five-day and six-day production week periods. Confidence intervals were constructed for the regression coefficients and null hypotheses were tested for the regression coefficients and the correlation coefficients.

The least-squares trend line for the linear regression of downtime ( $Y_i$ ) upon processing time ( $X_i$ ) for the five-day production weeks is illustrated in Figure 12. Values for the linear regression were calculated using standard methods and are as follows:

$n$	$= 24$	$a$	$= 1.9014$
$\bar{X}$	$= 29.1492$	$b$	$= -0.0376$
$\bar{Y}$	$= 0.8054$	$s_b$	$= 0.0322$
$s_{Y.X}$	$= 0.8873$	$r$	$= -0.2416$

Average length of processing time ( $\bar{X}$ ) for the five-day weeks was 29.1492 hours. Average amount of downtime ( $\bar{Y}$ ) lost during five-day weeks

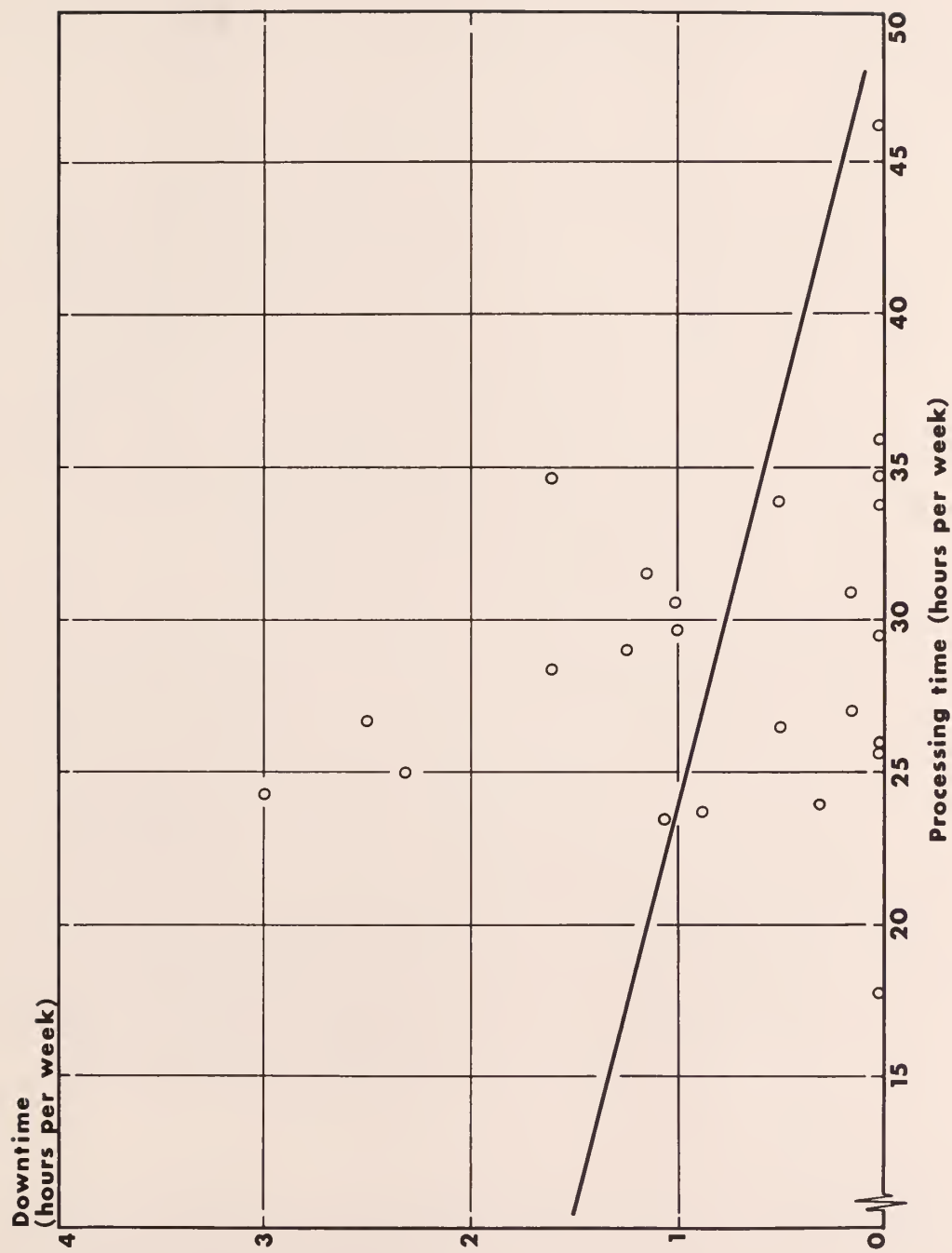


Fig. 12.--Twenty-four observations of dryer downtime per processing week obtained from case study plant production records for five-day processing weeks of varying duration with least-squares trend line indicated.



was 0.8054 hours. If the trend line was extended back to the Y-axis, the Y-intercept (a) would give an unrealistic literal interpretation of 1.9014 hours of downtime even if no processing was accomplished. The linear regression coefficient (b) would indicate a decrease of 0.0376 hours of downtime for each additional hour of processing time during a five-day week.

A ninety-five percent confidence interval was constructed for the regression coefficient of the five-day figures using the following confidence interval formula:

$$CI_{1-\alpha}: b - s_b \cdot t_{\alpha, n-2} \leq \beta \leq b + s_b \cdot t_{\alpha, n-2} \quad (3)$$

then:

$$CI_{95}: b - s_b \cdot t_{.05, 22} \leq \beta \leq b + s_b \cdot t_{.05, 22}$$

$$-0.0376 - 0.0322 \cdot 2.074 \leq \beta \leq -0.0376 + 0.0322 \cdot 2.074$$

$$-0.1044 \leq \beta \leq +0.0292$$

From this sample we can say, with ninety-five percent confidence, that the true value of the 5-day week regression coefficient lies between the values -0.1044 and +0.0292, inclusive.

Using a "t-test" for testing the hypothesis that the value of the true 5-day week regression coefficient is actually zero, in light of this particular sample, the following formula was used:

$$t_{n-2} = \frac{b - \beta}{s_b} \quad (4)$$

$$H_0: \beta = 0$$

$$H_a: \beta \neq 0$$

$$t_{22} = \frac{-0.0376 - 0}{0.0438} = 1.1677$$

This value is significant only at the sixty percent level and the hypothesis ( $H_0: \beta = 0$ ) was accepted for the five-day weeks.

The product-moment coefficient of linear correlation ( $r$ ) between downtime ( $Y_1$ ) and processing time ( $X_1$ ), is equal to -0.2416 for the five-day weeks. This is not an indication of a particularly high degree of linear association between downtime and processing time.

Using another "t-test" formula and the information from this sample, a test can be made of the null hypothesis that the true population value of the 5-day week correlation coefficient ( $\rho$ ) is equal to zero. In order for this test to be used validly it is necessary to assume that the pairs of values obtained in this sample of five-day weeks are actually samples from a normal bivariate population.

Statement of the null hypothesis and the formula to be used are as follows:

$$H_0: \rho = 0$$

$$H_a: \rho \neq 0$$

$$t_{n-2} = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \quad (5)$$

$$t_{22} = \frac{-0.2416\sqrt{22}}{\sqrt{1-0.0584}} = -1.1678$$

This value is significant only at the sixty percent level and the hypothesis ( $H_0: \rho = 0$ ) was accepted. There is no evidence in this sample sufficient to challenge a belief that there is no significant linear association between downtime and processing time.

The same type of analysis was made for the six-day weeks. The least-squares trend line for the linear regression of hours downtime in

a processing week ( $Y_1$ ) upon the hours of processing time in a processing week ( $X_1$ ) for the six-day weeks is shown in Figure 13. Values for the linear regression are as follows:

$n$	$= 19$	$a$	$= -1.1937$
$\bar{X}$	$= 50.1516$	$b$	$= 0.0870$
$\bar{Y}$	$= 3.1695$	$s_b$	$= 0.0464$
$s_{Y.X}$	$= 2.8657$	$r$	$= 0.4139$

Average length of processing time ( $\bar{X}$ ) for the six-day weeks was 50.1516 hours. Average amount of downtime ( $\bar{Y}$ ) lost during six-day weeks was 3.1695 hours. If the trend line was extended back to the Y-axis, the Y-intercept ( $a$ ) would give an impossible literal interpretation of -1.1937 hours of downtime when no processing was accomplished. The linear regression coefficient ( $b$ ) would indicate an increase of 0.0870 hours of downtime for each additional hour of processing time during a six-day week.

Using the same confidence interval formula as for the five-day weeks above, a ninety-five percent confidence interval was constructed for the regression coefficient of the six-day weeks.

$$CI_{95}: b - s_b \cdot t_{.05, 17} \leq \beta \leq b + s_b \cdot t_{.05, 17}$$

$$0.0870 - 0.0464 \cdot 2.110 \leq \beta \leq 0.0870 + 0.0464 \cdot 2.110$$

$$-0.0109 \leq \beta \leq +0.1849$$

From this sample we can say with ninety-five percent confidence that the true value of the six-day week regression coefficient lies somewhere between the values -0.0109 and +0.1849, inclusive.

Using the same "t-test" formula as for the five-day weeks above, the hypothesis was tested that the value of the true regression coefficient



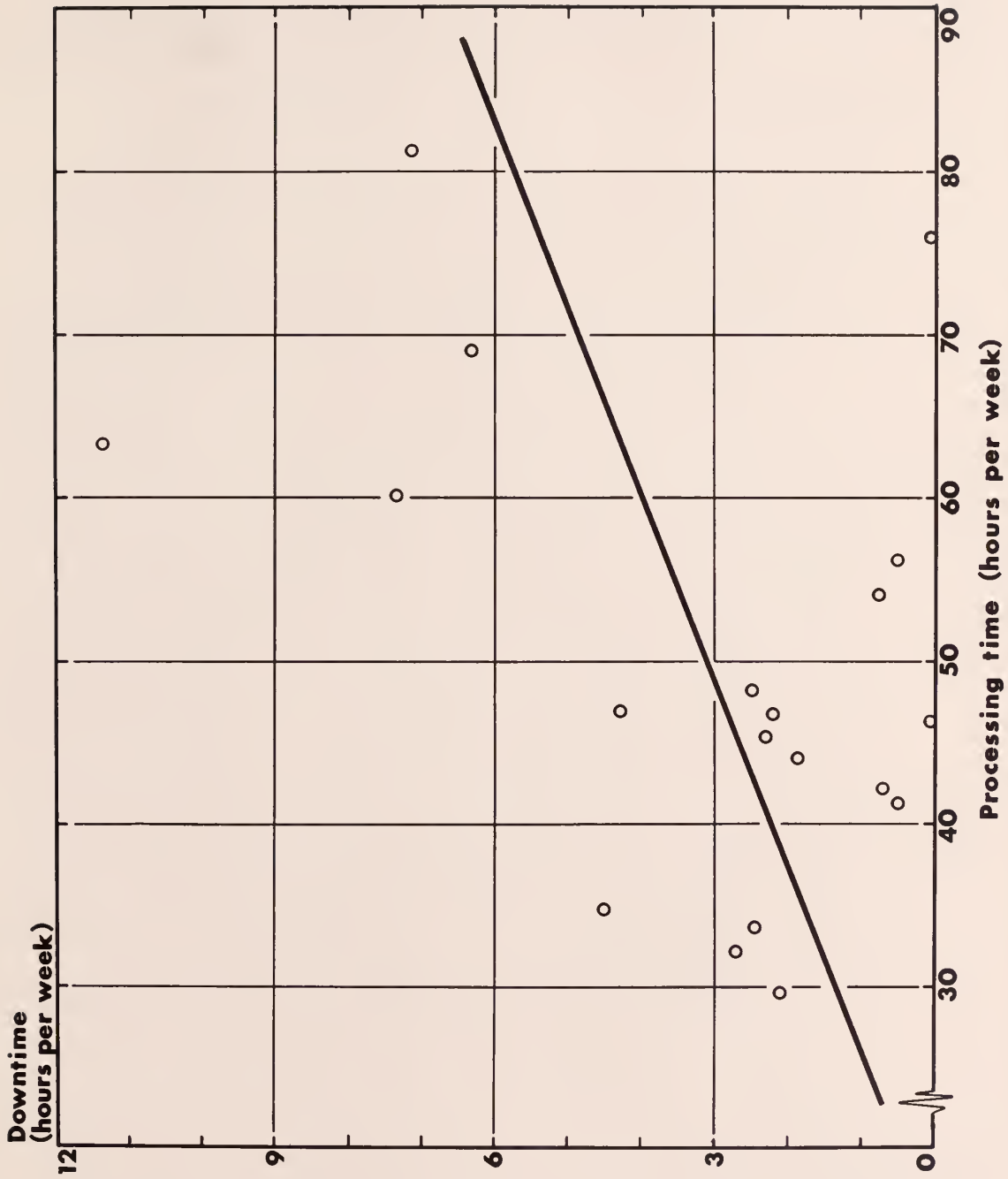


Fig. 13.--Nineteen observations of dryer downtime per processing week obtained from case study plant production records for six-day processing weeks of varying duration with least-squares trend line indicated.

is actually zero in light of this particular sample:

$$H_0: \beta = 0$$

$$H_a: \beta \neq 0$$

$$t_{17} = \frac{b - \beta}{s_b} = \frac{0.0870 - 0}{0.0464} = 1.8750$$

This value is significant only at the ninety percent level and the hypothesis ( $H_0: \beta = 0$ ) was also accepted for the six-day weeks. It may be noted that the six-day sample offered much more indication that the true value might be something other than zero. With a ten percent possibility of error, the hypothesis ( $H_0: \beta = 0$ ) could have been rejected for six-day weeks on the basis of this sample.

The product-moment coefficient of linear correlation ( $r$ ) between "X" and "Y" has a value of +0.4139 for the six-day weeks. This is an indication that the degree of linear association between downtime and processing time is greater than for the five-day weeks although it still is not a high degree of association.

Using the same "t-test" formula as for the five-day weeks above, a null hypothesis can be tested that the population correlation coefficient ( $\rho$ ) is actually zero. Again, as for the five-day weeks, in order to be valid this test must be based upon an assumption that the pairs of values that were obtained in this sample are samples from a normal bivariate population.

$$H_0: \rho = 0$$

$$H_a: \rho \neq 0$$

$$t_{n-2} = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} = \frac{0.4139\sqrt{19-2}}{\sqrt{1-0.1713}} = 1.8748$$

This value is significant only at the ninety percent level and the hypothesis ( $H_0: \rho = 0$ ) was accepted. Again it may be noted that this sample offered more evidence that the population correlation coefficient might actually be some value other than zero. The hypothesis could have been rejected in favor of its alternative ( $H_a: \rho \neq 0$ ) with a ten percent possibility of error.

### Ratio analysis of downtime

Least-squares trend lines calculated above represent the best "fit" that can be obtained for single, straight lines among the sample observations when comparing the sums of squares of the deviations from the trend lines. Even with the "best fitting" trend lines, however, it was not possible to successfully challenge a null hypothesis proposing "no relationship" between the observations of case study plant "downtime" and "processing time." On the basis of the sample data presented in Table 49 it must therefore be concluded that the relationship is essentially that of random occurrence.

However, it was also obvious from data in Table 49 that there tended to be a definite accumulation of downtime during operations of the case study plant even though it could not be adequately predicted by a linear relationship. This quantity of downtime for maintenance appeared to be of sufficient importance to warrant inclusion in cost calculations in some form. In recognition of this maintenance cost factor it was therefore decided to use a proportional relationship between periods of maintenance time and processing time based upon total quantities from Table 49. Calculation of this ratio can be indicated by the following notation:



$$\frac{\text{Total maintenance phase time}}{\text{Total processing time}} = \frac{\text{Average maintenance time}}{\text{Unit of processing time}} \cdot \quad (6)$$

It is not intended to imply by this relationship that each hour of processing time will be expected to be associated with a definite period of maintenance time. Instead, from data recorded by the case study plant, it appears reasonable to expect that maintenance time will tend to be experienced, over a period of time, in approximately the proportions recorded in Table 49.

A ratio such as indicated by notation (6) would be illustrated in either Figure 12 or 13 as a straight line having positive slope and passing through the origin of the coordinate system. It is recognized that the "fit" of this new relationship to the sample observations would not even be as good as the least-squares trend lines. The new proportionality relationship is more manageable, however, and would seem to be more justifiable over extended ranges of production.

Maintenance phase ratios calculated directly from data in Table 49 would not be completely appropriate for use in cost calculations. The dryer recording charts did not give an indication of the time required to shut down the drying stage for each "downtime" period. Although the point at which processing was terminated could be identified, the point at which the "shutting-down" phase was concluded was not indicated on the charts. Previous calculations therefore included both the "downtime" and the "shutting-down for downtime" periods under the single period referred to as "downtime."

Accurate specification of costs for the maintenance phases required a separation of these two types of periods, however. From observations of the operating practices and interviews with plant

personnel it was learned that an individual "shutting-down for downtime" phase usually required about one half the time that a "warm-up after downtime" phase would require. This approximation was used to adjust the original "downtime" definition by removing part of the time and allocating it to the new "shutting-down for downtime" phase definition.

Calculations used for adjusting the data originally presented in Table 49 can be indicated by the following notations:

$$\begin{array}{lcl} \text{Shutting-down for} & = & \frac{\text{Warm-up time (old)}}{2} \end{array} \quad (7)$$

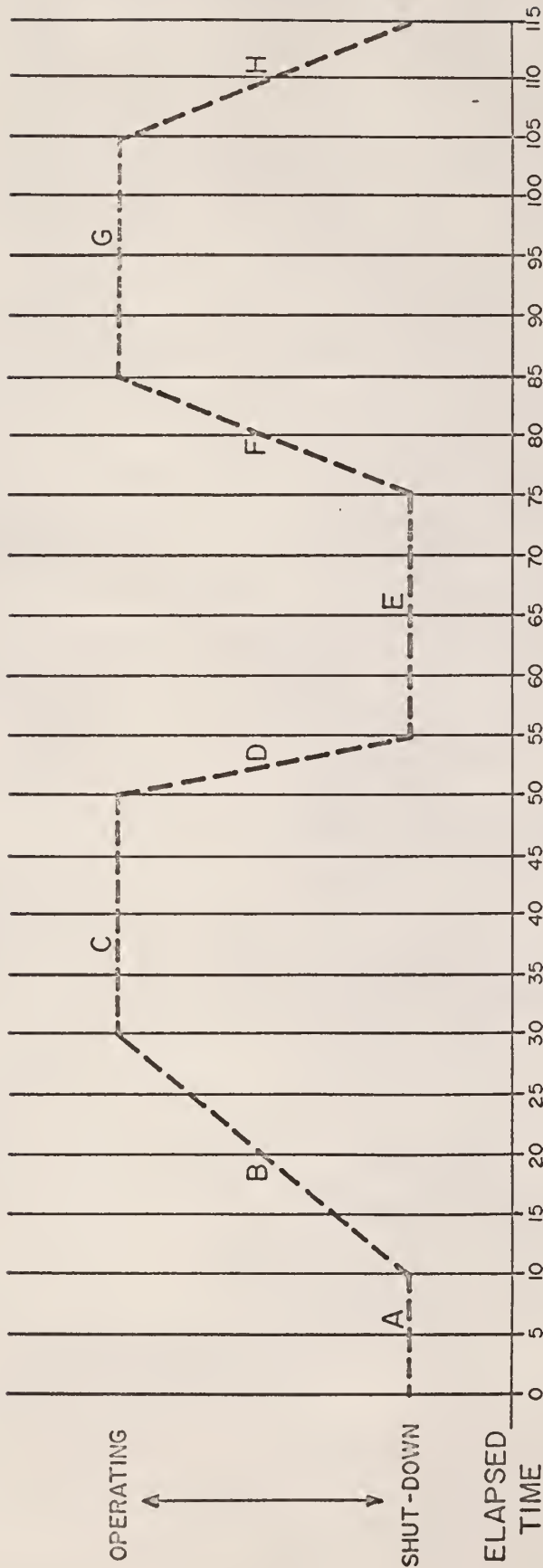
$$\begin{array}{lcl} \text{Downtime} & = & \text{Downtime} - \frac{\text{Warm-up time (old)}}{2} \\ \text{(new)} & & \text{(old)} \end{array} \quad (8)$$

$$\begin{array}{lcl} \text{Warm-up time} & = & \text{Warm-up time} \\ \text{(new)} & & \text{(old)} \end{array} \quad (9)$$

Application of these relationships to the "downtime" and "warm-up" periods originally presented in Table 49 produces a set of "synthetic" data to be used for the new definitions of "shutting-down for downtime", "downtime", and "warm-up after downtime" phases. Periods of time for the maintenance phases, calculated in the above manner, are presented in Table 50 and are denoted as " $Q_{ij}$ " for reference in further calculations.

TABLE 50.--Synthetic data developed for the new model plant maintenance phase definitions ( $Q_{ij}$ )

Phase (i)	Type of processing week (j)	
	5-day (j=1)	6-day (j=2)
Shutting-down for downtime (i=1) . . . .	3.12	9.08
Downtime (i=2) . . . .	16.21	51.04
Warm-up after downtime (i=3) . . . .	6.24	18.17



- A. Hook-up phase; approximately ten minutes per production run.
- B. Warm-up phase; approximately twenty minutes per production run.
- C. Processing period before down-time; indefinite period.
- D. Shutting-down for down-time phase; approximately five minutes per downtime.
- E. Down-time phase; indefinite period.
- F. Warm-up after down-time phase; approximately ten minutes per down-time.
- G. Processing period after down-time; indefinite period.
- H. Shutting-down phase; approximately ten minutes per production run.

Fig. 14.---Illustration of the relationship between production run phases of the drying stage showing a single "downtime" during a production run.



The quantities of maintenance phase periods ( $Q_{ij}$ ) from Table 50 can be used to calculate the ratios between the phase times and the total processing period of time. These ratios will be denoted as " $R_{ij}$ " and the necessary calculation can be indicated by the following notation:

$$R_{ij} = \frac{Q_{ij}}{P_{ij}} \quad (10)$$

where:

$R_{ij}$  = ratio of time assigned to the  $i^{\text{th}}$  maintenance phase and the  $j^{\text{th}}$  weekly definition to the total processing time,

$Q_{ij}$  = period of time assigned to the  $i^{\text{th}}$  phase and the  $j^{\text{th}}$  weekly definition (Table 50), and

$P_j$  = period of processing time for the  $j^{\text{th}}$  weekly definition (Table 49).

Values for the " $R_{ij}$ " ratios for each of the maintenance phases are presented in Table 51. Reference is made to these ratios for the calculation of the " $T_{ij}$ " values in Appendix D.

TABLE 51.--Ratios of model plant maintenance phase elapsed time to total elapsed processing phase time for five-day and six-day production weeks ( $R_{ij}$ )

Phase (i)	Types of processing week (j)	
	5-day (j=1)	6-day (j=2)
Shutting-down for downtime (i=1) . . .	0.0045	0.0095
Downtime (i=2) . . . .	0.0232	0.0536
Warm-up after downtime (i=3) . . .	0.0089	0.0191

## APPENDIX H

## Direct Processing Cost Element Requirements for a Production Run

The physical quantities of the different types of labor, utilities and supplies that were required for processing of the raw product "skim milk" will be presented in this appendix. These are the various cost elements that were responsible for the direct processing costs incurred by the plant during a production run. When unit prices from Appendix J are applied to these physical units in Part V, total direct cost for the production run is determined.

These direct cost elements are of a variable nature for the plant in the sense that the plant can elect to process or refrain from processing on a particular day. But these cost elements can themselves also be broken down again into cost elements for those phases of the production run which are of a fixed nature once the decision to process has been made, and the cost elements for those phases which are still variable in proportion to the quantity of product processed during that production run. Accordingly, these cost element requirements will be presented in two groups.

First will be presented cost element requirements for those phases showing fixed characteristics, and second will be presented those requirements for the phases showing variable characteristics. The presentation will be for each individual cost element by phases for each successive stage. Where differentiation of the product caused an observable change in processing requirements, variations are shown under the most broad type of differentiation applicable (i.e., fifty-pound plain, hundred-pound plain, or

hundred-pound vs. government bags; five-day vs. six-day weeks; truck vs. railroad car loading).

The definitions and descriptions of the various stages and phases were developed in Part III. Procedures used in determining processing cost element requirements were presented in Part IV.

#### Section I; Fixed cost element requirements

Cost element requirements presented in this section will be those for phases of each stage showing fixed characteristics during a production run. Totals for each stage are total requirements for the entire production run and are assumed not to vary regardless of the quantity of product produced, as long as it is greater than zero.

Table 10 of Part IV summarizes the fixed cost element requirements by stages.

#### A. Fixed class A labor requirements.

The notation which is to be followed for the labor requirements of each stage will be:

$$\left( \begin{array}{c} \text{Number} \\ \text{working} \\ \text{(men)} \end{array} \right) \left( \begin{array}{c} \text{Time} \\ \text{worked} \\ \text{(hours)} \end{array} \right) = \begin{array}{c} \text{Total} \\ \text{labor} \\ \text{(man hours)} \end{array}$$

#### Evaporating stage.--

##### Hookup phase.--

Class A (106):

$$1 \times 2.50 =$$

2.50 hrs.

##### Vacuum buildup phase.--

Class A (106):

$$1 \times 0.67 =$$

0.67

##### Warm-up phase.--

Class A (106):

$$1 \times 0.50 =$$

0.50

##### Shutting-down phase.--

Class A (106):

$$1 \times 0.67 =$$

0.67



Cleanup phase.--		
Class A (107):		
1 x 8.00 =	8.00 hrs.	
Total for Stage I:		12.34 hrs.
<u>Drying stage.--</u>		
Hookup phase.--		
Class A (104):		
1 x 0.17 =	0.17	
Warm-up phase.--		
Class A (104):		
1 x 0.17 =	0.17	
Shutting-down phase.--		
Class A (104):		
1 x 0.08 =	0.08	
Cleanup phase.--		
Class A (105):		
1 x 3.50 =	3.50	
Total for stage II:		3.92 hrs.
<u>Bagging stage.--</u>		
Setup phase.--		
Class A (104):		
1 x 0.10 =	0.10	
Shutting-down phase.--	None	
Cleanup phase.--		
Class A (104):		
1 x 0.33 =	0.33	
Total for stage III:		0.43
<u>Storage stage.--</u>		None
<u>Truck loading stage.--</u>		None
<u>Railroad car loading stage.--</u>		None

#### B. Fixed class B labor requirements

This section will follow the same notation used for class A labor.

<u>Evaporating stage.--</u>	None
<u>Drying stage.--</u>	None
<u>Bagging stage.--</u>	

Setup phase.--	
Class B (108):	
1 x 0.33 =	0.33 hrs.
Shutting-down phase.--	
Class B (108):	
1 x 0.08 =	0.08
Cleanup phase.--	None
Total for stage III:	0.41 hrs.
<u>Storage stage.--</u>	None
<u>Truck loading stage.--</u>	None
<u>Railroad car loading stage.--</u>	None

### C. Fixed class C labor requirements

This section will follow the same notation used for class A labor.

<u>Evaporating stage.--</u>	None
<u>Drying stage.--</u>	None
<u>Bagging stage.--</u>	
Setup phase.--	
50-lb. bag operations	
Class C (110):	
1 x 0.33 =	0.33
100-lb bag operations:	None
Shutting-down phase.--	
50-lb. bag operations:	
Class C (110):	
1 x 0.08 =	0.08
100-lb. bag operations:	None
Cleanup phase.--	None
Totals for stage III:	
50-lb. bag operations:	0.41
100-lb bag operations:	None
<u>Storage stage.--</u>	None
<u>Truck loading stage.--</u>	None
<u>Railroad car loading stage.--</u>	None

## D. Fixed electricity requirements

Electrical requirements which are fixed for the period of a production run are presented in units of kilowatt hours for each individual item of electrical equipment.<sup>1</sup> The notation that will be followed for each stage is:

$$\left( \begin{array}{c} \text{Operating} \\ \text{time} \\ \text{(hours)} \end{array} \right) \left( \begin{array}{c} \text{Power} \\ \text{usage} \\ \text{(KW)} \end{array} \right) = \text{Power requirement (KWH)}$$

### Evaporating stage.--

#### Hookup phase.--

Product removal pump (47):	
0.05 x 2.798 = 0.1399	
Portable fan (89):	
2.50 x 0.287 = 0.7175	
Roof fan no. 1 (90):	
2.50 x 1.066 = 2.6650	
Roof fan no. 2 (91):	
2.50 x 0.574 = 1.4350	
Roof fan no. 3 (92):	
2.50 x 0.574 = 1.4350	
Total for phase	6.3924 KWH

#### Vacuum buildup phase.--

Can-room pump (2):	
0.67 x 8.776 = 5.8799	
Input pump (9):	
0.67 x 2.798 = 1.8747	
Live steam heater pump (13):	
0.33 x 8.776 = 2.8961	
Hot-well pump (16):	
0.33 x 4.663 = 1.5388	
Condensor pump (42):	
0.67 x 35.106 = 23.5210	
Cooling tower #1 fan (44):	
0.33 x 8.776 = 2.8961	
Portable fan (89):	
0.67 x 0.287 = 0.1923	
Roof fan no. 1 (90):	
0.67 x 1.066 = 0.7142	
Roof fan no. 2 (91):	
0.67 x 0.574 = 0.3846	
Roof fan no. 3 (92):	
0.67 x 0.574 = 0.3846	
Total for phase:	40.2823

---

<sup>1</sup>The method used for calculating the "power usage" values is described in the "electrical requirements" section of Part IV.



## Warm-up phase.--

Can-room pump (2):

$$0.50 \times 8.776 = 4.3880$$

Input pump (9):

$$0.50 \times 2.798 = 1.3990$$

Live steam heater pump (13):

$$0.50 \times 8.776 = 4.3880$$

Hot-well pump (16):

$$0.50 \times 4.663 = 2.3315$$

1st-effect condensate pump (24):

$$0.50 \times 1.599 = 0.7995$$

2nd-eff. cond. &amp; 1st interstage heater pump (30):

$$0.50 \times 1.066 = 0.5330$$

3rd-eff. cond. &amp; 2nd interstage heater pump (34):

$$0.50 \times 1.066 = 0.5330$$

Vapor-heater cond. pump (38):

$$0.50 \times 1.066 = 0.5330$$

Condensor pump (42):

$$0.50 \times 35.106 = 17.5530$$

Cooling tower #1 fan (44):

$$0.50 \times 8.776 = 4.3880$$

Portable fan (89):

$$0.50 \times 0.287 = 0.1435$$

Roof fan no. 1 (90):

$$0.50 \times 1.066 = 0.5330$$

Roof fan no. 2 (91):

$$0.50 \times 0.574 = 0.2870$$

Roof fan no. 3 (42):

$$0.50 \times 0.574 = 0.2870$$

Total for phase:

52.4875 KWH

## Shutting-down phase.--

Hot-well pump (16):

$$0.25 \times 4.663 = 1.1658$$

1st-effect condensate pump (24):

$$0.67 \times 1.599 = 1.0713$$

2nd-eff. cond. &amp; 1st interstage heater pump (30):

$$0.67 \times 1.066 = 0.7142$$

3rd-eff. cond. &amp; 2nd inter. heater pump (34):

$$0.67 \times 1.066 = 0.7142$$

Vapor-heater cond. pump (38):

$$0.67 \times 1.066 = 0.7142$$

Condensor pump (42):

$$0.67 \times 1.066 = 0.7142$$

Cooling tower no. 1 fan (44):

$$0.67 \times 8.776 = 5.8799$$

Cooling tower no. 2 fan (46):

$$0.67 \times 4.663 = 3.1242$$

Product removal pump (47):

$$0.67 \times 2.798 = 1.8747$$

Portable fan (89):

$$0.67 \times 0.287 = 0.1923$$

Roof fan no. 1 (90):

$$0.67 \times 1.066 = 0.7142$$

Roof fan no. 2 (91):

$$0.67 \times 0.574 = 0.3846$$

Roof fan no. 3 (92):  
 $0.67 \times 0.574 = 0.3846$   
 Total for phase: 17.6484 KWH

Cleanup phase.--

Input pump (9):  
 $4.25 \times 2.798 = 11.8915$   
 Live steam heater pump (13):  
 $2.00 \times 8.776 = 17.5520$   
 Hot-well pump (16):  
 $2.00 \times 4.663 = 9.3260$   
 CIP pump no. 1 (102):  
 $3.33 \times 3.555 = 11.8382$   
 CIP pump no. 2 (103):  
 $0.83 \times 2.052 = 1.7032$   
 Portable fan (89):  
 $8.0 \times 0.287 = 2.2960$   
 Roof fan no. 1 (90):  
 $8.0 \times 1.066 = 8.5280$   
 Roof fan no. 2 (91):  
 $8.0 \times 0.574 = 4.5920$   
 Roof fan no. 3 (92):  
 $8.0 \times 0.574 = 4.5920$   
 Total for phase: 72.3189

Total for stage I: 189.1295 KWH

Drying stage.--

Hookup phase.-- None

Warm-up phase.--

High-pressure feed pump (51):  
 $0.25 \times 43.882 = 10.9705$   
 Air intake fan (54):  
 $0.33 \times 65.824 = 21.7219$   
 Gas burner fan (55):  
 $0.33 \times 17.553 = 5.7925$   
 Airlock motor no. 1 (60):  
 $0.17 \times 0.287 = 0.0488$   
 Airlock motor no. 2 (61): 0.0488  
 Airlock motor no. 3 (67): 0.0488  
 Airlock motor no. 4 (70): 0.0488  
 Airlock motor no. 5 (73): 0.0488  
 Airlock motor no. 6 (77): 0.0488  
 Airlock motor no. 7 (81): 0.0488  
 Sifter motor (82):  
 $0.17 \times 4.663 = 0.7927$   
 Transfer fan (83):  
 $0.33 \times 21.941 = 7.2405$   
 Exhaust fan (84):  
 $0.33 \times 87.765 = 28.9624$   
 Total for phase: 75.8221

## Shutting-down phase.--

High-pressure pump (51):

$$0.03 \times 43.882 = 1.3165$$

Air intake fan (54):

$$0.17 \times 65.824 = 11.1901$$

Gas burner fan (55):

$$0.17 \times 17.553 = 2.9840$$

Airlock motor no. 1 (60):

$$0.17 \times 287 = 0.0488$$

Airlock motor no. 2 (61): 0.0488

Airlock motor no. 3 (67): 0.0488

Airlock motor no. 4 (70): 0.0488

Airlock motor no. 5 (73): 0.0488

Airlock motor no. 6 (77): 0.0488

Airlock motor no. 7 (81): 0.0488

Sifter motor (82):

$$0.17 \times 4.663 = 0.7927$$

Transfer fan (83):

$$0.17 \times 21.941 = 3.7300$$

Exhaust fan (84):

$$0.17 \times 87.765 = 14.9200$$

Total for phase:

35.2749 KWH

## Cleanup phase.--

Portable utility pump (50):

$$1.25 \times 8.776 = 10.9700$$

High-pressure feed pump (51):

$$0.42 \times 43.882 = 18.4304$$

Total for phase:

29.4004

Total for stage II:

140.4974 KWH

Bagging stage.--

Setup phase.--

None

Shutting-down phase.--

Sewing machine motor (94):

$$0.08 \times 0.287 =$$

0.0230

Cleanup phase.--

None

Total for stage III:

0.0230

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

None

## E. Fixed natural gas requirements



Natural gas requirements are presented in units of cubic feet (cu. ft.) for each piece of equipment using gas. The notation which will be followed is:

$$\left( \begin{array}{c} \text{Operating} \\ \text{time} \\ \text{(hours)} \end{array} \right) \left( \begin{array}{c} \text{Average} \\ \text{usage} \\ \text{(cu. ft./hr.)} \end{array} \right) = \begin{array}{c} \text{Total} \\ \text{usage} \\ \text{(cu. ft.)} \end{array}$$

Evaporating stage.--

None

Drying stage.--

Hookup phase.--

None

Warm-up phase.--

Dryer burner and redryer (56, 65):

$$0.30 \times 9600 =$$

2880.0000 cu. ft.

Shutting-down phase.--

Dryer burner and redryer (56, 65):

$$0.03 \times 9600 =$$

288.0000

Cleanup phase.--

None

Total for stage II:

3168.0000 cu.ft.

Bagging stage.--

None

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

None

#### F. Fixed steam requirements

Steam requirements for each piece of equipment are presented in pounds of steam delivered at the boiler. An assumed distribution loss is incorporated into the "average usage" value for each item of equipment as described in the direct cost section. The notation to be followed is:

$$\left( \begin{array}{c} \text{Operating} \\ \text{time} \\ \text{(hours)} \end{array} \right) \left( \begin{array}{c} \text{Average} \\ \text{Usage} \\ \text{(lbs./hr.)} \end{array} \right) = \begin{array}{c} \text{Total} \\ \text{usage} \\ \text{(lbs.)} \end{array}$$

Evaporating stage.--

Hookup phase.--

None

## Vacuum buildup phase.--

Hogging jets (41):

$$0.67 \times 244.40 = 163.7480$$

Intermediate jets (39):

$$0.67 \times 441.10 = 295.5370$$

Live steam heater (14):

$$0.33 \times 1022.20 = 337.3260$$

Total for phase:

796.6110 lbs.

## Warm-up phase.--

Hogging jets (41):

$$0.25 \times 244.40 = 61.1000$$

Intermediate jets (39):

$$0.50 \times 441.10 = 220.5500$$

Live steam heater (14):

$$0.50 \times 1022.20 = 511.1000$$

Thermo-compressor (21):

$$0.50 \times 8361.10 = 4180.5500$$

Total for phase.

4973.3000

## Shutting-down phase.--

Intermediate jets (39):

$$0.25 \times 441.10 = 110.2750$$

Thermo-compressor (21):

$$0.25 \times 8361.10 = 2090.2750$$

Total for phase.--

2200.5500

## Cleanup phase.--

Live steam heater (14):

$$2.0 \times 1022.2 =$$

2044.4000

Total for stage I:

10014.8610 lbs.

Drying stage.--

None

Bagging stage.--

None

Storage stage.

None

Truck loading stage.--

None

Railroad car loading stage.--

None

## G. Fixed water requirements

Water requirements are estimates and are presented as a total for the complete phase or complete activity conducted within the phase (i.e., "wash down outside of evaporator").

Evaporating stage.--

## Hookup phase.--

Chlorine spray of the evaporator  
5 gals.

Wash pumps and input meter:  
10 gals.

Total for phase: 15 gals.

## Vacuum buildup phase.--

None

## Warm-up phase.--

None

## Shutting-down phase.--

Flush heater and lines: 75

## Cleanup phase.--

Alkali circulation:  
100 gals.

1st clear rinse:  
100 gals.

Acid rinse:  
100 gals.

2nd clear rinse:  
100 gals.

Wash down outside of evaporator:  
50 gals.

Total for phase: 450

Total for stage I: 540 gals.

Drying stage.--

## Hookup phase.--

None

## Warm-up phase.--

High pressure feed pump (51):  
500 gal.

0.25 hrs. x hr. 125

## Shutting-down phase.--

High-pressure feed pump (51):  
500 gals.

0.03 hrs. x hr. 15

## Cleanup phase.--

Flush lines from evaporator  
25 gals.

Clear rinse:  
150 gals.

Alkali circulation:  
60 gals.

High-pressure pump (51):  
500 gals. = 210 gals.

0.42 hr. x hrs.



Clear rinse:	
150 gals.	
Total for phase:	595 gals.
Total for stage II:	735 gals.
<u>Bagging stage.--</u>	
Setup phase.--	None
Warm-up phase.--	None
Shutting-down phase.--	None
Cleanup phase.--	
Wash down walls and floor:	100
Total for stage III:	100
<u>Storage stage.--</u>	None
<u>Truck loading stage.--</u>	None
<u>Railroad car loading stage.--</u>	None

#### H. Fixed chlorine requirements

<u>Evaporating stage.--</u>	
Hookup phase.--	
Chlorine for water spray	1.0 pt.
Vacuum buildup phase.--	None
Warm-up phase.--	None
Shutting-down phase.--	None
Cleanup phase.--	None
Total for stage I:	1.0 pt.
<u>Drying stage.--</u>	None
<u>Bagging stage.--</u>	None
<u>Storage stage.--</u>	None
<u>Truck loading stage.--</u>	None
<u>Railroad car loading stage.--</u>	None

## I. Fixed LC-10 acid cleaner requirements

<u>Evaporating stage.--</u>		
Hookup phase.--	None	
Vacuum buildup phase.--	None	
Warm-up phase.--	None	
Shutting-down phase.--	None	
Cleanup phase.--		
Circulation:	1.50 gal.	
Total for stage I:		1.50 gal.
<u>Drying stage.--</u>		None
<u>Bagging stage.--</u>		None
<u>Storage stage.--</u>		None
<u>Truck loading stage.--</u>		None
<u>Railroad car loading stage.--</u>		None

## J. Fixed Shur-spray acid cleaner requirements

<u>Evaporating stage.--</u>		None
<u>Drying stage.--</u>		
Hookup phase.--	None	
Warm-up phase.--	None	
Shutting-down phase.--	None	
Cleanup phase.--		
Circulation:	10.0 lbs.	
Total for stage II:		10.0 lbs.
<u>Bagging stage.--</u>		None
<u>Storage stage.--</u>		None
<u>Truck loading stage.--</u>		None
<u>Railroad car loading stage.--</u>		None

**K. Fixed alkali cleaner requirements**Evaporating stage.--

Hookup phase.--	None
Vacuum buildup phase.--	None
Warm-up phase.--	None
Shutting-down phase.--	None
Cleanup phase.--	
Circulation:	80.0 lbs.
Total for stage I:	80.0 lbs.

Drying stage.--

Hookup phase.--	None
Warm-up phase.--	None
Shutting-down phase.--	None
Cleanup phase.--	
Circulation:	10.0
Total for stage II:	10.0

<u>Bagging stage.--</u>	None
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<u>Storage stage.--</u>	None
-------------------------	------

<u>Truck loading stage.--</u>	None
-------------------------------	------

<u>Railroad car loading stage.--</u>	None
--------------------------------------	------

**L. Fixed 50-lb plain container requirements**

No 50-lb plain container requirements for fixed phases of any stage.

**M. Fixed 100-lb plain container requirements**

No 100-lb plain container requirements for fixed phases of any stage.

**N. Fixed 100-lb government container requirements**

No 100-lb government container requirements for fixed phases of any stage.



#### O. Fixed felt roofing paper requirements

No felt roofing paper requirements for fixed phases of any stage.

#### P. Fixed insecticide requirements

No insecticide requirements for fixed phases of any stage.

#### Q. Fixed lumber requirements

No lumber requirements for fixed phases of any stage.

### Section II: Variable cost element requirements

Cost element requirements presented in this section will be those for phases showing variable characteristics during a production run. Totals that are presented for each stage are total requirements of a particular cost element per hundred weight of finished product. This unit requirement is obtained in the following manner.

In general the figures presented for each item of equipment in the phase will represent the cost element requirement for a continuous hour of that phase. Total requirement for that item for a continuous hour of the phase is then multiplied by a factor ( $T_{ij}$ ) representing the length of time that particular phase that is required per hundred weight of final product.<sup>1</sup> This calculation can be represented in general terms as:

$$\left( \frac{\text{Total Requirement}}{\text{Phase Hour}} \right) (T_{ij}) = \frac{\text{Total Requirement}}{\text{Hundred-weight}}$$

All variable phases are handled in this manner even though phases other than the "operating" phases do not necessarily run for an hour at a time. The basis for this technique is presented in Appendix G.

Tables 11 and 12 of Part IV summarize these variable cost element requirements by stages for both five-day and six-day weeks.

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<sup>1</sup>See Table 41 of Appendix D for summary of " $T_{ij}$ " values.

# A. Variable class A labor requirements

The following notation will be used in presenting "variable" labor requirements for each phase of the first four stages:

$$\left( \begin{array}{c} \text{Number} \\ \text{working} \\ \text{(men)} \end{array} \right) \left( \begin{array}{c} \text{Time worked per} \\ \text{hour of phase} \\ \text{(hours/hour)} \end{array} \right) = \begin{array}{c} \text{Total labor per} \\ \text{phase hour} \\ \text{(man-hours/hour)} \end{array}$$

Total labor requirement per hour for each phase is converted to the basis of a hundredweight of product by the following calculation:

$$\left( \frac{\text{Man-hours}}{\text{phase hour}} \right) \left( T_{ij} \right) = \frac{\text{Man-hours}}{\text{cwt.}}$$

Evaporating stage.--

Operating phase.--

Class A (106):

$$1 \times 1.00 = 1.00 \text{ hr.}$$

$$1.00 \times T_{11} = 0.0287202536 \text{ hr.}$$

Total for stage I:

0.0287202536 hr.

Drying stage.--

Operating phase.--

Class A (104):

$$1 \times 0.08 = 0.08 \text{ hr.}$$

$$0.0022976202$$

$$0.08 \text{ hr.} \times T_{11} =$$

Shutting-down for maintenance phase.--

5-day weeks:

Class A (104):

$$1 \times 1.00 = 1.00 \text{ hr.}$$

$$1.00 \text{ hr.} \times T_{21} = 0.0001292411$$

6-day weeks:

Class A (104):

$$1 \times 1.00 = 1.00 \text{ hr.}$$

$$1.00 \text{ hr.} \times T_{22} = 0.0002728424$$

Downtime for maintenance phase.--

5-day weeks:

Class A (104):

$$1 \times 1.00 = 1.00 \text{ hr.}$$

$$1.00 \text{ hr.} \times T_{31} = 0.0006663099$$

6-day weeks:

Class A (104):

$$1 \times 1.00 = 1.00 \text{ hr.}$$

$$1.00 \text{ hr.} \times T_{32} = 0.0015394056$$

Warm-up after downtime phase.--

5-day weeks

Class A (104):

$1 \times 1.00 = 1.00 \text{ hr.}$

$1.00 \text{ hr.} \times T_{41} = 0.0002556103 \text{ hr.}$

6-day weeks:

Class A (104):

$1 \times 1.00 = 1.00 \text{ hr.}$

$1.00 \text{ hr.} \times T_{42} = 0.0005485568$

Totals for stage II:

5-day weeks:

0.0033487815 hr.

6-day weeks:

0.0046584250

Bagging stage.--

Operating phase.--

Class A (104):

$1 \times 0.92 = 0.92 \text{ hr.}$

$0.92 \text{ hr.} \times T_{11} = 0.0264226333$

Shutting-down for dryer maintenance phase.-- None

Downtime for dryer maintenance phase.-- None

Warm-up after dryer maintenance phase.-- None

Total for stage III:

0.0264226333

Storage stage.--

Truck loading stage.

Operating phase.--

Class A (104):

$1 \times 1.00 = 1.00 \text{ hr.}$

$1.00 \text{ hr.} \times T_{11} = 0.0029570968$

Total for stage V:

0.0029570968

Railroad car loading stage.--

Operating phase:

Class A (104):

$1 \times 1.00 = 1.00 \text{ hrs.}$

$1.00 \text{ hrs.} \times T_{11} = 0.0062500000$

Total for stage VI:

0.0062500000

## B. Variable class B labor requirements

Class B labor will follow the same notation used for class A labor.



Evaporating stage.--

None

Drying stage.--

Operating phase.--

None

Shutting-down for maintenance phase.--None

Downtime for maintenance phase.--

5-day weeks:

Class B (108):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{31} = 0.0006663099 \text{ hr.}$ 

6-day weeks:

Class B (108):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{32} = 0.0015394056 \text{ hr.}$ 

Warm-up after downtime phase.--

None

Totals for stage II

5-day weeks:

0.0006663099 hr.

6-day weeks

0.0015394056

Bagging stage.--

Operating phase.--

Class B (108)

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{11} =$ 

0.0287202536

Shutting-down for dryer maintenance phase.--

5-day weeks:

Class B (108):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \times T_{21} = 0.0001292411$ 

6-day weeks:

Class B (108)

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \times T_{22} = 0.0002728424$ 

Downtime for dryer maintenance phase.--None

Warm-up after dryer downtime phase.--

5-day weeks:

Class B (108):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{41} = 0.0002556103$ 

6-day weeks:

Class B (108):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{42} = 0.0005485568$

Totals for stage III:

5-day weeks:

0.0291051050 hr.

6-day weeks:

0.0295416528

Storage stage.--

None

Truck loading stage.--

Operating phase.--

Class B (108)

1 x 1.00 = 1.00 hr.

1.00 hr. x  $T_{11}$  =

0.0029570968 hr.

Total for stage V:

0.0029570968

Railroad car loading stage.--

Operating phase.--

Class B (108):

1 x 1.00 = 1.00 hrs.

1.00 hrs. x  $T_{11}$  =

0.0062500000

Total for stage VI:

0.0062500000

#### C. Variable class C labor requirements

Class C labor will follow the same notation used for class A labor.

Evaporating stage.--

None

Drying stage.--

Operating phase.--

None

Shutting-down for maintenance phase.--None

Downtime for maintenance phase.--

5-day weeks:

50-lb. bags:

Class C (110):

1 x 1.00 = 1.00 hr.

1.00 hr. x  $T_{31}$  =

0.0006663099

100-lb bags:

None

6-day weeks:

50-lb bags:

Class C(110):

1 x 1.00 = 1.00 hr.

1.00 hr. x  $T_{32}$  =

0.0015394056

100-lb bags:

None

Warm-up after downtime phase.--

None

## Totals for stage II:

## 5-day weeks:

50-lb bags:

0.0006663099 hr.

100-lb bags:

None

## 6-day weeks:

50-lb bags:

0.0015394056

100-lb bags:

None

Bagging stage.

## Operating phase.--

## 50-lb bags:

Class C (110):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{11} =$ 

0.0287202536 hr.

100-lb bags:

None

## Shutting-down for dryer maintenance phase.--

## 5-day weeks:

50-lb bags:

Class C (110):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{21} =$ 

0.0001292411

100-lb bags:

None

## 6-day weeks:

50-lb bags:

Class C (110):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{22} =$ 

0.0002728424

100-lb bags:

None

## Downtime for dryer maintenance phase.--None

## Warm-up after dryer downtime phase.--

## 5-day weeks:

50-lb bags:

Class C (110):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{41} =$ 

0.0002556103

100-lb bags:

None

## 6-day weeks:

50-lb bags:

Class C (110):

 $1 \times 1.00 = 1.00 \text{ hr.}$  $1.00 \text{ hr.} \times T_{42} =$ 

0.0005485568

100-lb bags:

None

## Totals for stage III:

## 5-day weeks:

50-lb bags:

0.0291051050

100-lb bags:

None

## 6-day weeks:

50-lb bags:

0.0295416528

100-lb bags:

None



Storage stage.--

None

Truck loading stage.--

Operating phase.--

Class C (110):

$$1 \times 1.00 = 1.00 \text{ hr.}$$

$$1.00 \text{ hr.} \times T_{11} = 0.0029570968 \text{ hr.}$$

Total for stage V:

0.0029570968 hr.

Railroad car loading stage.--

Operating phase.--

Class C (111):

$$4 \times 1.00 = 4.00 \text{ hrs.}$$

$$4.00 \text{ hrs.} \times T_{11} = 0.0250000000$$

Total for stage VI:

0.0250000000

**D. Variable electricity requirements**

The following notation will be used in presenting variable labor requirements for each item of equipment in each phase:

$$\left( \begin{array}{c} \text{Operating time per} \\ \text{hour of phase} \\ \text{(hour/hour)} \end{array} \right) \left( \begin{array}{c} \text{Power} \\ \text{usage} \\ \text{(KW)} \end{array} \right) = \begin{array}{c} \text{Total power requirement} \\ \text{per phase hour} \\ \text{(KWH/hour)} \end{array}$$

Total power requirement per hour for each phase is converted to the basis of a hundredweight of product by the following calculation.

$$\left( \frac{\text{Total power}}{\text{Phase hour}} \right) \left( T_{1j} \right) = \frac{\text{Average power requirement}}{\text{Cwt.}}$$

Evaporating stage.--

Operating phase.--

Can-room pump (2):

$$1.0 \text{ hr.} \times 8.776 \text{ KW} = 8.776 \text{ KWH}$$

Input pump (9)

$$1.0 \times 2.798 = 2.798$$

Live steam heater pump (13):

$$1.0 \times 8.776 = 8.776$$

Hot-well pump (16):

$$1.0 \times 4.663 = 4.663$$

1st condensate pump (24):

$$1.0 \times 1.599 = 1.599$$

2nd condensate and 1st interstage pump (30):

$$1.0 \times 1.066 = 1.066$$

3rd condensate and 2nd interstage pump (34):

$$1.0 \times 1.066 = 1.066$$

Vapor heater pump (38):

$$1.0 \times 1.066 = 1.066$$

Condensor pump (42):

$$1.0 \times 35.106 = 35.106$$

Cooling tower no. 1 fan (44):

$$1.0 \times 8.776 = 8.776$$

Cooling tower no. 2 fan (46):

$$1.0 \times 4.663 = 4.663$$

Product removal pump (47):

$$1.0 \times 2.798 = 2.798$$

Portable fan (89):

$$1.0 \times 0.287 = 0.287$$

Roof fan no. 1 (90):

$$1.0 \times 1.066 = 1.066$$

Roof fan no. 2 (91)

$$1.0 \times 0.574 = 0.574$$

Roof fan no. 3 (92):

$$1.0 \times 0.574 = 0.574$$

Total for phase:

$$83.654 \times T_{11} =$$

2.4025640946 KWH

Total for stage I:

2.4025640946 KWH

Drying stage.--

Operating phase.--

High-pressure feed pump (51):

$$1.0 \times 43.882 = 43.882 \text{ KWH}$$

Air intake fan (54):

$$1.0 \times 65.824 = 65.824$$

Gas burner fan (55):

$$1.0 \times 17.553 = 17.553$$

Airlock motor no. 1 (60):

$$1.0 \times 0.287 = 0.287$$

Airlock motor no. 2 (61): 0.287

Airlock motor no. 3 (67): 0.287

Airlock motor no. 4 (70): 0.287

Airlock motor no. 5 (73): 0.287

Airlock motor no. 6 (77): 0.287

Airlock motor no. 7 (81): 0.287

Sifter motor (82):

$$1.0 \times 4.663 = 4.663$$

Transfer fan (83):

$$1.0 \times 21.941 = 21.941$$

Exhaust fan (84):

$$1.0 \times 87.765 = 87.765$$

Total for phase

$$243.637 \times T_{11} =$$

6.9973164263

Shutting-down for maintenance phase.--

High-pressure feed pump (51):

$$1.0 \times \frac{2 \text{ (minutes running time)}}{5 \text{ (minutes complete phase)}} \times 43.882 = 17.553$$

Air intake fan (54):  
 $1.0 \times 65.824 = 65.824$   
 Gas burner fan (55):  
 $1.0 \times 17.553 = 17.553$   
 Airlock motor no. 1 (60):  
 $1.0 \times 0.287 = 0.287$   
 Airlock motor no. 2 (61): 0.287  
 Airlock motor no. 3 (67): 0.287  
 Airlock motor no. 4 (70): 0.287  
 Airlock motor no. 5 (73): 0.287  
 Airlock motor no. 6 (77): 0.287  
 Airlock motor no. 7 (81): 0.287  
 Sifter motor (82):  
 $1.0 \times 4.663 = 4.663$   
 Transfer fan (83):  
 $1.0 \times 21.941 = 21.941$   
 Exhaust fan (84):  
 $1.0 \times 87.765 = 87.765$   
 Totals for phase:  
 5-day weeks:  
 $217.308 \times T_{21} = 0.0280851249 \text{ KWH}$   
 6-day weeks:  
 $217.308 \times T_{22} = 0.0592908363$   
 Downtime for maintenance phase.-- None

Warm-up after downtime phase.--  
 High pressure feed pump (51):  
 $1.0 \times 43.882 \times \frac{2 \text{ (minutes running time)}}{10 \text{ (minutes complete phase)}}$   
 $= 8.776 \text{ KWH}$   
 Air intake fan (54):  
 $1.0 \times 65.824 = 65.824$   
 Gas burner fan (55):  
 $1.0 \times 17.553 = 17.553$   
 Airlock motor no. 1 (60):  
 $1.0 \times 0.287 = 0.287$   
 Airlock motor no. 2 (61): 0.287  
 Airlock motor no. 3 (67): 0.287  
 Airlock motor no. 4 (70): 0.287  
 Airlock motor no. 5 (73): 0.287  
 Airlock motor no. 6 (77): 0.287  
 Airlock motor no. 7 (81): 0.287  
 Sifter motor (82):  
 $1.0 \times 4.663 = 4.663$   
 Transfer fan (83):  
 $1.0 \times 21.941 = 21.941$   
 Exhaust fan (84):  
 $1.0 \times 87.765 = 87.765$   
 Totals for phase:  
 5-day weeks:  
 $208.531 \times T_{41} = 0.0533026715$



6-day weeks:

$$208.531 \times T_{42} =$$

0.1153910980 KWH

Totals for stage II:

5-day weeks:

7.0787042227 KWH

6-day weeks:

7.1719983606

Bagging stage.--

Operating phase.--

Sewing machine motor (94):

$$1.0 \times 0.287 = 0.287$$

Moisture tester (95):

$$\frac{5 \text{ (min. running time)}}{60 \text{ minutes}} \times 2.500$$

$$= 0.2083$$

Total for phase:

$$0.4953 \times T_{1j}$$

0.0142251416

Shutting-down for dryer maintenance phase.--

Sewing machine motor (94):

$$1.0 \times 0.287 = 0.287$$

Totals for phase

5-day weeks:

$$0.287 \times T_{21} =$$

0.0000370922

6-day weeks:

$$0.287 \times T_{22} =$$

0.0000783058

Downtime for dryer maintenance phase None

Warm-up after dryer downtime phase.--

Sewing machine motor (94):

$$1.0 \times 0.287 = 0.287$$

Totals for phase:

5-day weeks:

$$0.287 \times T_{41} =$$

0.0000733602

6-day weeks

$$0.287 \times T_{42} =$$

0.0001574358

Totals for stage III:

5-day weeks:

0.0143355940

6-day weeks:

0.0144608832

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.

None

## E. Variable natural gas requirements

Notation to be used in presenting variable natural gas requirements will be similar to that which was used for fixed natural gas requirements:

$$\left( \begin{array}{c} \text{Operating time per} \\ \text{hour of phase} \\ \text{hour/hour} \end{array} \right) \left( \begin{array}{c} \text{Gas requirement} \\ \text{per hour} \\ \text{cu. ft./hour} \end{array} \right) = \begin{array}{c} \text{Total gas requirement} \\ \text{per phase hour} \\ \text{(cu. ft./hour)} \end{array}$$

The total gas consumption per hour for each phase is converted to the basis of a hundredweight of product by the following calculation:

$$\left( \frac{\text{Total gas requirement}}{\text{Phase hour}} \right) (T_{1j}) = \frac{\text{Average gas requirement}}{\text{Unit of product (cwt.)}}$$

Evaporating stage.--

None

Drying stage.--

Operating phase.--

Dryer and redrier burners (56, 65):

$$1.0 \times 9600 = 9600$$

Total for phase:

$$9600 \times T_{11} = 275.7144345600 \text{ cu.ft.}$$

Shutting-down for maintenance phase.--

Dryer and redrier burners (56, 65):

$$1.0 \times \frac{2 \text{ (min. running time)}}{5 \text{ (min. complete phase)}} \times 3000 = 1200$$

Totals for phase:

5-day weeks:

$$1200 \times T_{21} = 0.1550893200$$

6-day weeks:

$$1200 \times T_{22} = 0.3274108800$$

Downtime for maintenance phase.--

None

Warm-up after downtime phase.--

Dryer and redrier burners (56, 65):

$$1.0 \times \frac{8 \text{ (min. running time)}}{10 \text{ (min. complete phase)}} = 0.80 \text{ hr.} \times 9600 = 7680$$

Totals for phase:

5-day weeks:

$$7680 \times T_{41} = 1.9630871040$$

6-day weeks:

$$7680 \times T_{42} = 4.2129162240$$

Totals for stage II:

5-day weeks:

$$277.8326109840$$

6-day weeks:

$$280.2547616640$$

Bagging stage.--

None

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

None

**F. Variable steam requirements**

The notation to be used in presenting variable steam requirements is as follows:

$$\left( \begin{array}{c} \text{Operating time per} \\ \text{hour of phase} \\ \text{(hour/hour)} \end{array} \right) \left( \begin{array}{c} \text{Steam Requirement} \\ \text{per hour} \\ \text{(lbs./hour)} \end{array} \right) = \begin{array}{c} \text{Total steam requirement} \\ \text{per phase hour} \\ \text{(lbs./hour)} \end{array}$$

The total steam requirement per hour of each phase is then put on the basis of a hundredweight of product by the following conversion.

$$\left( \frac{\text{Total steam requirement}}{\text{Phase hour}} \right) (T_{ij}) = \frac{\text{Average steam requirement}}{\text{Unit of product (cwt)}}$$

Evaporating stage.--

Operating phase.--

Intermediate jets (39):

$$1.0 \times 397.0000 = 397.0000$$

Live steam heater (14):

$$1.0 \times 920.0000 = 920.0000$$

Thermo-compressor (21):

$$1.0 \times 7525.0000 = 7525.0000$$

Total for phase:

$$8842.0000 \times T_{11} =$$

$$253.9444823312\#$$

Total for stage I:

$$253.9444823312$$

Drying stage.--

None

Bagging stage.--

None

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

None

**G. Variable water requirements**

The notation to be used in presenting variable water requirements is as follows:



$$\left( \begin{array}{c} \text{Operating time per} \\ \text{hour of phase} \\ \text{(hour/hour)} \end{array} \right) \left( \begin{array}{c} \text{Water requirement} \\ \text{per hour} \\ \text{(gal./hour)} \end{array} \right) = \begin{array}{c} \text{Total water requirement} \\ \text{per phase hour} \\ \text{(gal./hour)} \end{array}$$

Total water requirement per hour for each phase is converted to the basis of a hundredweight of product by the following calculation:

$$\left( \frac{\text{Total water requirement}}{\text{Phase hour}} \right) (T_{ij}) = \frac{\text{Average water requirement}}{\text{Unit of product (cwt.)}}$$

Evaporating stage.--

None

Drying stage.--

Operating phase.--

None

Shutting-down for maintenance phase.--

High-pressure feed pump (51):

$$\begin{aligned} & 1.0 \text{ hr.} \times \frac{2 \text{ (min. running time)}}{5 \text{ (min. total phase)}} \\ & = .4 \text{ hr.} \times \frac{500 \text{ gal.}}{\text{hr.}} = 200 \text{ gal.} \end{aligned}$$

Totals for phase:

5-day weeks:

$$200 \times T_{21} = 0.0258482200 \text{ gal.}$$

6-day weeks:

$$200 \times T_{22} = 0.0545684800 \text{ gal.}$$

Downtime for maintenance phase.-- None

Warm-up after downtime phase.--

High-pressure feed pump (51):

$$\begin{aligned} & 1.0 \text{ hr.} \times \frac{6 \text{ (min. running time)}}{10 \text{ (min. total phase)}} \\ & = .6 \text{ hr.} \times \frac{500 \text{ gal.}}{\text{hr.}} = 300 \text{ gal.} \end{aligned}$$

Totals for phase:

5-day weeks:

$$300 \times T_{41} = 0.0766830900$$

6-day weeks:

$$300 \times T_{42} = 0.1645670400$$

Totals for stage II:

5-day weeks:

0.1025313100

6-day weeks:

0.2191355200

Bagging stage.--

None

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

None

**H. Variable chlorine requirements**

No chlorine requirements for variable phases of any stage.

**I. Variable LC-10 acid cleaner requirements**

No LC-10 requirements for variable phases of any stage.

**J. Variable Shur spray acid cleaner requirements**

No Shur-spray requirements for variable phases of any stage.

**K. Variable alkali cleaner requirements**

No alkali cleaner requirements for variable phases of any stage.

**L. Variable 50-lb plain container requirements**

<u>Evaporating stage.--</u>	None
<u>Drying stage.--</u>	None
<u>Bagging stage.--</u>	
Operating phase.--	
<u>2 bags</u> =	2.00 bags
cwt powder	
Shutting-down for dryer maintenance phase.--	None
Downtime for dryer maintenance phase.--	None
Warm-up after dryer maintenance phase.--	None
Total for stage III:	2.00 bags.
<u>Storage stage.--</u>	None
<u>Truck loading stage.--</u>	None
<u>Railroad car loading stage.--</u>	None

**M. Variable 100-lb plainer container requirements**

<u>Evaporating stage.--</u>	None
<u>Drying stage.--</u>	None
<u>Bagging stage.--</u>	

Operating phase.--

$\frac{1 \text{ bag}}{\text{cwt powder}} = 1.00 \text{ bag}$

Shutting-down for dryer maintenance phase.-- None

Downtime for dryer maintenance phase.-- None

Warm-up after dryer maintenance phase.--None

Total for stage III: 1.00 bag

Storage stage.-- None

Truck loading stage.-- None

Railroad car loading stage.-- None

#### N. Variable 100-lb government container requirements

Evaporating stage.-- None

Drying stage.-- None

Bagging stage.--

Operating phase.--

$\frac{1 \text{ bag}}{\text{cwt powder}} = 1.00 \text{ bag}$

Shutting-down for dryer maintenance phase.-- None

Downtime for dryer maintenance phase.--None

Warm-up after dryer maintenance phase.--None

Total for stage III: 1.00 bag

#### O. Variable felt roofing paper requirements

Evaporator stage.-- None

Drying stage.-- None

Bagging stage.-- None

Storage stage.-- None

Truck loading stage.-- None

Railroad car loading stage.--



Operating phase.--

$\frac{1 \text{ roll}}{800.0000 \text{ cwt}} =$

0.0012500000 roll

Total for stage VI:

0.0012500000  
roll

P. Variable insecticide requirements

Evaporating stage.--

None

Drying stage.--

None

Bagging stage.--

None

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

Operating phase.--

$\frac{0.25 \text{ pint}}{800.0000 \text{ cwt. powder}} =$

0.0003125000 pt.

Total for stage VI:

0.0003125000 pt.

Q. Variable lumber requirements

Evaporating stage.--

None

Drying stage.--

None

Bagging stage.--

None

Storage stage.--

None

Truck loading stage.--

None

Railroad car loading stage.--

Operating phase.--

$\frac{46.6667 \text{ board ft.}}{800.0000 \text{ cwt. powder}} =$

0.0583333333  
bd. ft.

Total for stage VI:

0.0583333333  
bd. ft.

## APPENDIX I

## Utility Rate Schedules

Rate schedules for electricity, natural gas, and water are presented in this section for reference in Appendix J. These rate schedules are not necessarily those experienced by the case study plant and no claim is made for any particular degree of representativeness for the individual schedules.

Electricity rate schedule

Schedule PP-1 for Large Primary Service for the Kansas Power and Light Company as filed with the State Corporation Commission of Kansas was used for electricity rates. The pertinent sections of this schedule are reproduced below.

AVAILABILITY:

This schedule is available to Customers who contract for primary power service and who guarantee a demand of not less than 175 KVA.

CHARACTER OF SERVICE:

Alternating current, 60 cycle, three phase, delivery and measurement through one point of delivery at not less than 2300 volts.

NET MONTHLY RATE:

## A. Demand Charge:

First	175 KVA of Demand	\$1.40 per KVA
Next	425 KVA of Demand	\$1.10 per KVA
Excess	KVA of Demand	\$ .90 per KVA

## B. Energy Charge:

First	50 KWHs per KVA of Demand @ 1.20¢ per KWH
-------	---

Next	100 KWHs per KVA of Demand @	.85¢ per KWH
Next	250 KWHs per KVA of Demand @	.65¢ per KWH
Excess	KWHs @	.55¢ per KWH

### C. Minimum Bill:

The minimum monthly bill shall be the demand charge for 50% of the contract demand as stated in Customer's service contract, but in no case shall it be calculated on less than 175 KVA; provided, that should the Customer exceed such contract demand during six months or more of any yearly contract period, then a new contract demand shall be determined and used as the basis for the minimum monthly bill for the next yearly contract period.

### DETERMINATION OF BILLING DEMAND:

Demand shall be measured and shall be the average of the four highest 30 minute integrated rates of consumption in kilowatts divided by the average power factor during the four 30 minute periods aforementioned.

### FUEL COST ADJUSTMENT:

For each 1¢ that the average cost of fuel to the Company in any one month exceeds 17¢ or is less than 15¢ per million BTU, the energy charge per KWH shall be increased or decreased, as the case may be, by that fraction of a cent which results from the application of the following formula:

$$\frac{\text{BTU per KWH Output}}{1,000,000 \text{ BTU}} \times 1¢$$

The cost of fuel as used herein shall be the cost as burned in Company's generating stations, which shall include storage and handling costs and the net cost of removing refuse.

### PAYMENT:

Bills will be rendered NET, bearing the last date upon which net payment may be made, namely, 10 days after date distributed. When payment is made after that date, 2% will be added to the net amount of the bill.

### CONTRACT:

Customers receiving service under this price schedule shall sign a contract effective for one year or more.

### RULES AND REGULATIONS:

Service hereunder is subject to the Company's Rules and Regulations on file with The State Corporation Commission of Kansas.



Natural gas rate schedule

Schedule GGa-64 for General Gas Service of the Kansas Power and Light Company as filed with the State Corporation Commission of Kansas was used for natural gas rates. The pertinent sections of this schedule are reproduced below.

AVAILABLE

At points on the Company's existing distribution mains located within or adjacent to Group "a" communities (see index); or available at points located on parcels of land crossed by Company's gas transmission lines which are an integral part of its interconnected gas transmission system (main system) provided Customer has executed the standard contract for "Gas Service from Transmission Lines."

APPLICABLE

To customers using natural gas service on a firm basis supplied at one point of delivery and for which no specific schedule is provided.

NET MONTHLY BILLRate

\$2.00 for the first	1 MCF or less
.51 for MCF for the next	19 MCF
.42 for MCF for the next	80 MCF
.35 for MCF for all additional	MCF

Minimum

\$2.00

Tax Adjustment

Service hereunder is subject to the Company's "Tax Adjustment" Schedule.

PAYMENT

Monthly bills will be payable in accordance with the Company's Rules and Regulations.

MCF DEFINED

MCF means one thousand cubic feet of natural gas. A cubic foot of gas for billing purposes is defined as that quantity of gas

which fills one cubic foot of space at an absolute pressure of 14.65 pounds per square inch at a temperature of 60 degrees Fahrenheit. The Company may assume that the gas delivered obeys Boyle's Law and that atmospheric pressure is 14.4 pounds per square inch and that the flowing temperature of the gas in the meter is 60 degrees Fahrenheit.

#### OTHER TERMS AND CONDITIONS

Service hereunder is subject to the Company's Rules and Regulations on file with the State Commission of Kansas.

#### Water rate schedule

The currently effective water rate schedule for Manhattan, Kansas was used for water. Manhattan does not make a monthly meter charge for each meter. The only charge is for actual water usage in excess of the minimum bill. The rate schedule is reproduced with both the original volumes in cubic feet and converted to gallons (7.5 gals./cu. ft.).

TABLE 52.--Water rate schedule for the city of Manhattan, Kansas

Monthly water usage		Water charges			
		Inside city		Outside city	
		Per MCF.	Per 1,000 gals.	Per MCF.	Per 1,000 gals.
Cubic feet	Gallons				
0- 400	0- 3,000	\$1.50 <sup>a</sup>	\$0.20 <sup>a</sup>	\$3.00 <sup>a</sup>	\$0.40 <sup>a</sup>
401- 1,500	3,001- 11,250	4.00	0.53	8.00	1.07
1,501-40,000	11,251-300,000	2.70	0.36	5.40	0.72
Over 40,000	Over 300,000	2.00	0.27	4.00	0.53

<sup>a</sup> Minimum bill.

## APPENDIX J

### Cost Element Unit Prices

The price per unit for each of the cost elements considered in this study will be developed and presented in this appendix. Where utility rate schedules are involved (i.e., electricity, natural gas, and water), the unit price to be assigned will reflect application of a demand, such as might be experienced by an entire multi-product dairy plant of the type studied, to the rate schedules of Appendix I.

Unit prices for other cost elements are generally representative of prices that might be expected by a plant of this type in the mid-west.

#### Labor

The selection and ranking of job classifications and unit wages for the model plant are similar to those observed in the case study plant. Individual job locations have been assigned key numbers running consecutive to the key numbers assigned to individual equipment items presented in Table 38. Each of these labor positions is classified into either class A, B, or C types of positions and assigned a wage in Table 54.

#### Electricity

Rate schedule PP-1, Large Primary Service (Appendix I), of the Kansas Power and Light Company was used in establishing the unit



price to be used in calculations of electrical costs for the model plant. Reference to Table 53 indicates a two-year average electrical requirement for the entire case study plant equal to 195,333 KWH. As an approximation to this figure, the model plant was assumed to be associated with a multi-product dairy plant using approximately 200,000 KWH of electricity monthly and requiring a 600 KVA demand rating.

The unit charge for electricity can be obtained from the rate schedule of Appendix I and the previous two assumptions in the manner to be illustrated.

Monthly demand charge (600 KVA assumed)

First 175 KVA demand:

$$175 \text{ KVA} \times \frac{\$1.40}{\text{KVA}} = \$245.000$$

Next 425 KVA demand:

$$425 \text{ KVA} \times \frac{\$1.10}{\text{KVA}} = \$467.50$$

Total monthly demand charge: \$712.50

Energy charge (200,000 KWH/600 KVA = 333 KWH/KVA assumed)

First 50 KWH/KVA demand:

$$\frac{50 \text{ KWH}}{\text{KVA}} \times 600 \text{ KVA} \times \frac{\$0.0120}{\text{KWH}} = \$360.00$$

Next 100 KWH/KVA demand:

$$\frac{100 \text{ KWH}}{\text{KVA}} \times 600 \text{ KVA} \times \frac{\$0.0085}{\text{KWH}} = \$510.00$$

Next 183 KWH/KVA demand:

$$\frac{183 \text{ KWH}}{\text{KVA}} \times 600 \text{ KVA} \times \frac{\$0.0065}{\text{KWH}} = \$713.70$$

Total energy charge: \$1,583.70

Total monthly charge: \$2,296.20

Average monthly charge per KWH:

$$\frac{\text{Charge}}{\text{KWH}} = \frac{\text{Total charge}}{\text{Total KWH}} = \frac{\$2,296.20}{200,000 \text{ KWH}} = \$0.011481 \text{ per KWH.}$$

Natural gas

Rate schedule GGA-64, General Gas Service (Appendix I), of the Kansas Power and Light Company was used in establishing the unit price to be used in calculations of natural gas costs for the model plant. Reference to Table 53 gives the two-year average of gas usage for the entire plant.

This two-year average of 10,730 MCF per month was used to establish the unit price for natural gas in the following manner.

Monthly bill (10,730 MCF assumed):

First 1 MCF:

$$1 \text{ MCF} \times \frac{\$2.00}{\text{MCF}} = \$2.00$$

Next 19 MCF:

$$19 \text{ MCF} \times \frac{\$0.51}{\text{MCF}} = \$9.69$$

Next 80 MCF:

$$80 \text{ MCF} \times \frac{\$0.42}{\text{MCF}} = \$33.60$$

Next 10,630 MCF:

$$10,630 \text{ MCF} \times \frac{\$0.35}{\text{MCF}} = \$3,720.50$$

Total monthly bill:

\$3,765.79

Average monthly charge per cubic foot:

$$\frac{\text{Charge}}{\text{Cubic foot}} = \frac{\text{Total charge}}{\text{Total cubic feet}} = \frac{\$3,765.79}{10,730,000 \text{ cu. ft.}}$$

= \$0.000351 per cu. ft.

Table 53.--Utility requirements for entire case study plant as  
obtained from plant records

Month	Electricity (KWH)	Natural gas (MCF)
1962		
July . . . . .	262,400	12,683
August . . . . .	256,800	12,447
September . . . . .	222,400	10,528
October . . . . .	184,800	9,718
November . . . . .	176,800	10,305
December . . . . .	145,600	10,420
1963		
January . . . . .	160,800	8,199
February . . . . .	177,600	8,075
March . . . . .	148,000	9,230
April . . . . .	158,400	99,952
May . . . . .	195,200	10,489
June . . . . .	223,200	11,451
July . . . . .	216,800	9,478
August . . . . .	231,200	9,576
September . . . . .	180,000	8,492
October . . . . .	166,400	7,989
November . . . . .	174,800	10,289
December . . . . .	156,000	10,463
1964		
January . . . . .	178,400	10,341
February . . . . .	184,800	12,597
March . . . . .	177,600	10,609
April . . . . .	202,400	13,672
May . . . . .	248,000	15,300
June . . . . .	260,000	15,242
Total	4,688,000	257,545
Average	195,333	10,731



Table 54.--Labor classifications, positions, key numbers and wages assigned for the model plant

Key	Position	Classification	Wage
104	Dryer operator	Class A	\$1.70/hour
105	Dryer cleanup man	Class A	1.70/hour
106	Evaporator operator	Class A	1.70/hour
107	Evaporator cleanup man	Class A	1.70/hour
108	Powder bagger	Class B	1.60/hour
109	Boilerman	Class C	1.50/hour
110	Assistant powder bagger	Class C	1.50/hour
111-114	Bag handlers for powder loading	Class C	1.50/hour

#### Steam

The unit price for steam was synthetically calculated from the operation characteristics of the steam generating equipment in the case study plant and reference to engineering specifications for the equipment. The resulting price per unit of steam is an approximation to the cost of steam production for the plant and is not the result of a detailed cost study. Since steam cost is not a major element in the overall cost of dry milk processing, however, this method of cost estimation was considered adequate in light of the resources available to the study.

The boiler selected for use in the steam cost calculations for the model plant was the largest of three boilers in use by the case study plant. Made by Bigelow, the boiler was rated at 250 boiler horsepower (bhp.) and considered capable of operation at two hundred percent of rated capacity. For this study, it was assumed to be operating at a capacity equivalent to a 450 boiler horsepower rating and to be the sole source of steam for the operation of the

evaporator although usage of the steam from this boiler was not limited to the evaporator.

Technical data and values for the equipment involved in steam production are as follows:

Boiler . . . . .	Bigelow
Boiler horsepower . . . . .	450 bhp.
Boiler pressure . . . . .	110 psig.
Atmospheric pressure . . . . .	14.7 psib.
Absolute pressure (psia.) . . . . .	psib. + psig.
Feed water temperature . . . . .	90° F.
Combined boiler efficiency <sup>1</sup> . . . . .	75%
Btu. per cubic foot (Texas gas) <sup>2</sup> . . . . .	1,000 Btu.

#### Variable cost

The variable cost per pound of steam production was developed from individual cost element costs. Cost elements which were considered for the steam cost calculations were labor, electricity, natural gas, and water. Unit prices used for each of these cost elements (except water) are developed elsewhere in this appendix as follows:

Labor (class C) . . . . .	150¢ per hr.
Electricity . . . . .	1.1481¢ per KWH

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<sup>1</sup>Carl D. Shields, Boilers: Types, Characteristics and Functions (New York: F. W. Dodge Corporation, 1961), p. 495.

<sup>2</sup>Kolmer and Homme, 20.

Natural gas . . . . . 0.0351¢ per cu. ft.  
 Water . . . . . No charge<sup>1</sup>

Labor cost per hour.--One man (110, class C labor) was in attendance at the three case study plant boilers at all times during operation. It was assumed that one third of his \$1.50 per hour wages could be assigned to the cost of steam from this boiler.

Total hourly labor cost:

$$\left( \frac{1 \text{ hr. labor}}{\text{hour}} \right) \left( \frac{150¢}{\text{hour labor}} \right) (0.33) = 50¢ \text{ per hour.}$$

Electricity cost per hour.--The power requirements for the electrical motors were as follows:<sup>2</sup>

Two 15 hp. motors:

$$2 \times 13.165 \text{ KWH} = 26.330 \text{ KWH}$$

Two 5 hp. motors:

$$2 \times 4.663 \text{ KWH} = 9.326 \text{ KWH}$$

One 7.5 hp. motor:

$$1 \times 6.582 \text{ KWH} = \underline{6.582 \text{ KWH}}$$

$$\text{Total electricity} \quad 42.238 \text{ KWH}$$

Total hourly electricity cost:

$$\left( \frac{42.238 \text{ KWH}}{\text{hour}} \right) \left( \frac{1.14815¢}{\text{KWH}} \right) = 48.4934¢ \text{ per hour.}$$

<sup>1</sup>The case study plant was equipped to reuse condensate from the evaporator. The moisture removed from the milk is adequate to supply the boiler feed water requirements and therefore no charge will be made. This assumption is examined further under the "Water cost per hour" heading of this section.

<sup>2</sup>See "electrical requirements" section of Part IV.



Natural gas cost per hour.--Since there was no practical method available to this study for accurately determining the gas consumption of the boiler under load it was decided to use engineering formulas and specifications for an approximation.

The quantity of water which will be evaporated by boiler under specified conditions can be determined by a fixed relationship which has been established between water evaporated and commercial boiler horsepower (bhp.). A boiler must be capable of evaporating 29.50 pounds of water at 90°F. into steam at 110 psig. hourly for each rated horsepower.<sup>1</sup> The hourly evaporating capacity of the boiler used for this study was determined from this relationship:

$$\begin{aligned} \text{Pounds water} &= \left( \frac{29.50 \text{ lbs. water/hr.}}{1.0 \text{ bhp.}} \right) (450 \text{ bhp.}) \\ \text{evaporated hourly} &= 13,275 \text{ lbs. water per hour} \end{aligned}$$

The volume of gas required for this hourly rate of evaporation was determined by calculating the total amount of heat needed for the above evaporation. This required consideration of the sensible heat, latent heat, and total heat required for the formation of steam.

"Sensible heat" is the energy that is required in order to raise the temperature of water from its original temperature to 212°F. and is the first way that heat is expended in the production of steam. The second and third ways that heat is expended are in the formation of steam and in the expansion of the steam against atmospheric pressure. The sum of energy expended in the second and third ways is defined as "latent heat." The sum of the heat-units in water at its original

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<sup>1</sup>Walter B. Snow, Steam-boiler Practice (New York: John Wiley & Sons, 1904), p. 147.

temperature and in steam that is generated from it is defined as "total heat".<sup>1</sup>

The total heat contained in a pound of steam under the conditions assumed for this boiler (124.7 psia. and 343.89°F.) is equal to 1,218.82 Btu.<sup>2</sup> The sensible heat present in the feed water (assumed to have a temperature of 90°F.) is equal to 90.06 Btu. per pound of water.<sup>3</sup> The amount of heat required to raise a pound of water from 90°F. to saturated steam under these assumed boiler temperature and pressure conditions is equal to the difference between total heat in the steam and sensible heat in the feed water.

$$\begin{aligned}\text{Heat required} &= \left( \frac{\text{Total heat}}{\text{lb. steam}} \right) - \left( \frac{\text{Sensible heat}}{\text{lb. feed water}} \right) \\ &= 1,218.82 \text{ Btu.} - 90.06 \text{ Btu.} \\ &= 1,128.76 \text{ Btu.}\end{aligned}$$

The total amount of heat required for an hour's operation was determined by applying this requirement to the total number pounds of water evaporated hourly as derived above.

$$\begin{aligned}\frac{\text{Total heat}}{\text{Hour}} &= \frac{13,275 \text{ lbs. water}}{\text{Hour}} \times \frac{1,128.76 \text{ Btu.}}{\text{Lb. water}} \\ &= 14,984,289 \text{ Btu. per hour.}\end{aligned}$$

This total heat must be adjusted for the efficiency of the boiler. There are two losses of heat within the boiler. Inefficiencies of combustion prevent extraction of all potential heat energy in the

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<sup>1</sup>Ibid., 17.

<sup>2</sup>Ibid., 21.

<sup>3</sup>Ibid., 16.

fuel and inefficiencies of the boiler heat transfer prevent all of the heat of combustion from being transferred to the feed water. The combined "efficiency of the boiler" is the "ratio of the heat absorbed and appearing in the vapor to the heat supplied in the fuel burned".<sup>1</sup>

A seventy-five percent combined efficiency was assumed for the boiler used in this study. Application of this correction to the total heat required by the feed water produces the total heat required from the fuel.

$$\begin{aligned}\frac{\text{Total fuel heat}}{\text{Hour}} &= \frac{\text{Total heat (feed water)}/\text{hour}}{\text{Efficiency of the boiler}} \\ &= \frac{14,984,289 \text{ Btu.}/\text{hour}}{0.75} \\ &= 19,979,520 \text{ Btu. per hour}\end{aligned}$$

The final step in determining the hourly volume of fuel required when using natural gas was to divide the hourly heat requirement by the potential heat content of the natural gas. Texas natural gas is generally accepted to contain at least 1,000 Btu. per cubic foot of gas.

$$\frac{\text{Cubic feet}}{\text{Hour}} = \frac{19,979,520 \text{ Btu.}/\text{hour}}{1,000 \text{ Btu./ cu.ft.}} = 19,980 \text{ cu.ft. per hour.}$$

The hourly cost for natural gas was determined by applying the unit cost of natural gas to the hourly volume of natural gas.

$$\begin{aligned}\frac{\text{Natural gas cost}}{\text{Hour}} &= \left( \frac{19,980 \text{ cu.ft.}}{\text{Hour}} \right) \left( \frac{0.0351¢}{\text{Cu.ft.}} \right) \\ &= 701.2980¢ \text{ per hour.}\end{aligned}$$

Water cost per hour.--The feed water required for boiler operation can be calculated from the above relationship between boiler

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<sup>1</sup>C. W. Gordon, "Boiler," The Encyclopedia Americana, ed. A. H. McDannald, IV (1946), p. 169.



horsepower and feed water evaporated.

The hourly water requirement would be:

$$(450 \text{ bhp.}) \left( \frac{29.50 \text{ lbs. water}}{\text{Bhp.}} \right) = 13,275 \text{ lbs. water.}$$

Condensate from the evaporator was being returned to the boilers to be reused as boiler feed water make-up but the quantity was not being measured. It was assumed, however, that the actual amount was well in excess of the feed water requirements for this boiler.<sup>1</sup> An approximation for total volume of water extracted by the evaporator can be developed in the following manner.

Assuming:

39,090.617 lbs. skim per hour,<sup>2</sup>

0.089774 lb. solids per lb. skim,<sup>3</sup>

No solids losses in the evaporator, and

0.4300 lb. solids per lb. condensed product,<sup>4</sup> then

$$\begin{aligned} \frac{\text{Lbs. cow water removed}}{\text{Hour}} &= \frac{\text{Lbs. skim}}{\text{Hour}} - \frac{\text{Lbs. condensed product}}{\text{Hour}} \\ &= \frac{39,090.6711 \text{ lbs.}}{\text{Hour}} - \left( \frac{\left( \frac{39,090.6711 \text{ lbs.}}{\text{Hour}} \right) \left( \frac{0.089774 \text{ lb.}}{\text{Lb. skim}} \right)}{\frac{0.4300 \text{ lb. solids}}{\text{Lb. condensed product}}} \right) \end{aligned}$$


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<sup>1</sup>The water removed from the fluid milk in the evaporator was popularly referred to as "cow water."

<sup>2</sup>Table 44, Appendix E.

<sup>3</sup>Appendix E.

<sup>4</sup>Assumed content of the condensed product (Appendix B).

$$= \frac{39,090.6711 \text{ lbs.}}{\text{Hour}} - \frac{8,161.2119 \text{ lbs.}}{\text{Hour}}$$

$$= 30,929.4592 \text{ lbs. water per hour.}$$

Although not all condensate from the evaporator was clear enough to be saved, it was quite reasonable to assume that this boiler could rely completely upon "cow water" for the 13,275 lbs. of feed water required hourly and therefore no water charge was made.

Summary of variable costs.--The hourly charges made for all cost elements can be totaled to equal total variable cost per hour of operation.

Labor cost per hour	50.0000¢
Electricity cost per hour	48.4934¢
Natural gas cost per hour	701.2980¢
Water cost per hour	<u>No charge</u>
Total variable cost per hour	799.7914¢

Average variable cost is found by dividing this total hourly cost figure by the hourly steam production. Operating at full load the boiler is assumed to be converting 13,275 pounds of feed water into 13,275 pounds of steam hourly.

Thus, the average variable cost per pound of steam delivered at the boiler would be as follows:

$$\begin{aligned} \text{Average variable cost} &= \frac{\text{Total hourly variable cost}}{\text{Total hourly production}} \\ &= \frac{799.7914\text{¢/hour}}{13,275 \text{ lbs. steam/hour}} \\ &= 0.0602\text{¢ per lb. steam} \end{aligned}$$

#### Fixed cost

Fixed costs taken into consideration were depreciation and general overhead. The charge made for depreciation was based upon an

initial cost of \$14,928 assigned to this boiler.<sup>1</sup> A depreciation period of twelve years was used to obtain an annual depreciation charge of \$1,244.<sup>2</sup> General overhead included interest, insurance, taxes, and repairs, and was figured as a straight eight percent of initial cost.<sup>3</sup> This resulted in an annual general overhead charge of \$1,194. No charge was made for the building in which the boiler was installed.

The unit charge for fixed costs was determined by dividing this total fixed cost of \$2,438 by the annual steam production assumed for this boiler. If two weeks out of a fifty-two week year can be allotted to holidays, and if full eight-hour processing is assumed for a six-day week, there would be 300 operating days and 2,400 operating hours in a year. If the boiler is further assumed to operate at full capacity for the entire eight-hour day an annual steam production of 31,860,000 lbs. would result.

Average fixed cost can be calculated as follows:

$$\begin{aligned} \frac{\text{Average fixed cost}}{\text{Pound Steam}} &= \frac{\text{Total fixed cost}}{\text{Annual steam production}} \\ &= \frac{243,800¢}{31,860,000 \text{ lbs.}} = 0.0076¢ \text{ per lb. steam.} \end{aligned}$$

<sup>1</sup>Using original cost and the price index for "Machinery and Motive Products" from the Survey of Current Business compiled by the U.S. Department of Commerce.

<sup>2</sup>U.S. Treasury Department, Internal Revenue Service, Depreciation: Guidelines and Rules (No. 456; 1962), pp. 11-12.

<sup>3</sup>Snow, 4.



### Average cost

The average cost per pound of steam is an addition of the average variable cost and the average fixed cost under the assumed conditions.

$$\begin{aligned}\text{Average cost} &= \text{Average variable cost} + \text{Average fixed cost} \\ &= 0.0602\text{¢/lb.} + 0.0076\text{¢/lb.} \\ &= 0.0678\text{¢ per lb.}\end{aligned}$$

This unit cost for steam will be altered by variations in the quantity of steam assumed to be produced in a year. By illustration, if annual production of steam was reduced by one-half, unit cost would increase to 0.0831¢ per pound of steam.

The unit charge for steam to be used for this study will be 0.0678¢ per pound as calculated above. This steam is considered to be delivered at the boiler site. The steam requirement figures for individual items of equipment have been calculated in such a manner as to reflect an assumed efficiency for the plant distribution system.<sup>1</sup>

### Water

The municipal rate schedule for Manhattan, Kansas (Appendix I), was used in establishing the unit price for water.

Water usage for the case study plant was estimated by the plant engineer from his experience with the plant operating characteristics. The plant used three private water wells for the major portion of its water supply. These three wells pumped to a small reservoir with a recovery rate of 8,400 gallons per hour.

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<sup>1</sup>See "steam requirement" section of Part IV.

During peak water usage hours the private water well capacity was supplemented by drawing from the city water main. The private wells were adequate for the major portion of plant operations.

An approximation of the daily water usage was obtained by assuming that all three private wells pumped at full capacity for a complete eight-hour working day. This abstracts from an under-capacity of the wells during peak usage hours, under-utilization during a large portion of the working day, and some additional requirements occurring outside of the eight-hour working day.

Water requirement for a four-week month was approximated by the following procedure:

$$\frac{8,400 \text{ gal.}}{\text{hour}} \times \frac{8 \text{ hr.}}{\text{day}} \times \frac{6 \text{ days}}{\text{week}} \times \frac{4 \text{ weeks}}{\text{month}} = 1,612,800 \text{ gal. per month.}$$

In order to establish the unit price for water, it was assumed that it would be necessary for the model plant to purchase its total water requirement from a municipal water source. Reference to Appendix I indicates that the above monthly usage would be charged at the rate of \$0.27 per 1,000 gallons for a plant located within the city of Manhattan, Kansas. This is the figure that was used in the cost calculations of Part V.

### Containers

Representative costs used for the paper and plastic containers in which powder was bagged were approximately equivalent to current prices.

Table 55.--Unit prices assigned to powder containers for model plant cost calculations

Cost element	Lot size	Price per unit
50-lb. plain bags . . . . .	10,000	\$0.013725/bag
100-lb. plain bags . . . . .	10,000	0.022775/bag
100-lb. government bags . . . . .	5,000	0.068180/bag

### Supplies

Representative costs used for supplies in this study were approximately equivalent to current prices.

Table 56.--Unit prices assigned to supplies for model plant cost calculations

Cost element	Price per unit
HC-90 alkali cleaner . . . . .	\$ 6.250000/cwt.
Shur-spray acid cleaner . . . . .	22.440000/cwt.
LC-10 acid cleaner . . . . .	3.060000/gal.
XY-12 chlorine . . . . .	0.910000/gal.
Malathion insecticide . . . . .	3.580000/pint
Felt roofing paper . . . . .	3.500000/roll
Lumber (1 x 4 pine) . . . . .	0.016667/board ft.



Table 57.--Summary of unit prices assigned to the direct cost elements  
for use in the model plant cost calculations of Part V

Cost element	Price per unit
<b>Labor:</b>	
Class A . . . . .	\$1.700000/hour
Class B . . . . .	1.600000/hour
Class C . . . . .	1.500000/hour
<b>Utilities:</b>	
Electricity . . . . .	0.011481/KWH
Natural gas . . . . .	0.000351/cu.ft.
Steam . . . . .	0.000678/lb.
Water . . . . .	0.000270/gal.
<b>Containers:</b>	
50-lb. plain . . . . .	0.013725/bag
100-lb. plain . . . . .	0.022775/bag
100-lb. gov't . . . . .	0.068180/bag
<b>Supplies:</b>	
XY-12 chlorine . . . . .	0.910000/pint
LC-10 acid cleaner . . . . .	3.060000/gal.
Shur-spray acid cleaner . . . . .	0.224400/lb.
HC-90 alkali cleaner. . . . .	0.062500/lb.
Felt roofing paper . . . . .	3.500000/roll
Malathion insecticide . . . . .	3.580000/pint
Lumber (1 x 4 pine) . . . . .	0.016667/bd.ft.

## APPENDIX K

United States Standards for Grades  
of Nonfat Dry Milk (Spray Process)

Excerpts from standards set for nonfat dry milk by the Dairy Division of the Agricultural Marketing Service are presented in part in this appendix.<sup>1</sup>

58.525. Nonfat dry milk. "Nonfat dry milk" is the product resulting from the removal of fat and water from milk, and contains the lactose, milk proteins, and milk minerals in the same relative proportions as in the fresh milk from which made. It contains not over 5 percent by weight of moisture. The fat content shall not exceed 1-1/2 percent by weight.

(a) The term "milk" when used in this subpart means fresh, sweet milk produced by healthy cows, that has been pasteurized before or during the manufacture of the nonfat dry milk. (Nonfat dry milk covered by these standards shall not contain butter-milk or any added preservative, neutralizing agent or other chemical.)

## U.S. Grades

58.526. Nomenclature of U.S. grades. The nomenclature of U.S. grades is as follows:

U.S. Extra.

U.S. Standard.

58.527. Basis for determination of U.S. grades. (a) The U.S. grades of nonfat dry milk--spray process--are determined on the basis of flavor and odor, physical appearance, bacterial estimate on the basis of standard plate count, butterfat content, moisture content, scorched particle content, solubility index and titratable acidity.

(b) The final U.S. grade shall be established on the basis of the lowest rating of any one of the quality characteristics.

58.528. Requirements for U.S. grades of nonfat dry milk. (a) U.S. Extra. U.S. Extra grade shall conform to the following requirements:

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<sup>1</sup>U.S. Department of Agriculture, Agricultural Marketing Service, "United States Standards for Grades of Nonfat Dry Milk (Spray Process)," quoted in Federal Register, May 23, 1958.

(1) **Flavor and odor (applies to reliquified form):** Shall be sweet, pleasing and desirable but may possess the following flavors to a slight degree: chalky, cooked, feed and flat. . . .

(2) **Physical appearance:** Shall possess a uniform white to light cream natural color; free from lumps except those that readily break up with very slight pressure, and practically free from visible dark particles. The reliquified product shall be free from graininess. . . .

(3) **Laboratory test:** Shall be used to determine classification of the following quality characteristics:

(i) **Bacterial estimate:** Not more than 50,000 per gram standard plate count.

(ii) **Butterfat content:** Not more than 1.25 percent.

(iii) **Moisture content:** Not more than 4.00 percent.

(iv) **Scorched particle content:** Not more than 15.00 mg.

(v) **Solubility index:** Not more than 1.2 ml.

(vi) **Titratable acidity:** Not more than 0.15 percent. . . .

(b) **U.S. Standard.** U.S. Standard grade shall conform to the following requirements:

(1) **Flavor and odor (applies to reliquified form):** Should possess a fairly pleasing flavor but may possess the following flavors to a slight degree: Bitter, oxidized, stale, storage, utensil, and scorched; the following to a definite degree: Chalky, cooked, feed, and flat. . . .

(2) **Physical appearance:** May possess a slight unnatural color; free from lumps except those that break up readily under slight pressure and reasonably free from visible dark particles. The reliquified product shall be reasonably free from graininess. . . .

(3) **Laboratory tests:** Shall be used to determine classification of the following quality characteristics:

(i) **Bacterial estimate:** Not more than 100,000 per gram standard plate count.

(ii) **Butterfat content:** Not more than 1.50 percent.

(iii) **Moisture content:** Not more than 5.0 percent.

(iv) **Scorched particle content:** Not more than 22.5 mg.

(v) **Solubility index:** Not more than 2.0 ml.

(vi) **Titratable acidity:** Not more than 0.17 percent. . . .

58.529. **U.S. Grade not assignable.** Nonfat dry milk which fails to meet the requirements for U.S. Standard Grade and/or shows a direct microscopic clump count exceeding 300 million per gram shall not be assigned a U.S. grade.

58.537. **Explanation of terms--(a) With respect to flavor--(1) Slight.** Detected only upon critical examination.

(2) **Definite.** Easily detectable but not intense.

(3) **Bitter.** Similar to taste of quinine.

(4) **Chalky.** A tactual type of flavor, lacking in characteristic milk flavor.

(5) **Cooked.** Similar to a custard flavor and imparts a smooth aftertaste.

(6) **Feed.** Characteristic of the feed flavors in milk carried through into the nonfat dry milk.

(7) **Flat.** Lacking characteristic sweetness or full flavor.

(8) **Oxidized.** A flavor resembling cardboard and sometimes referred to as "cappy" or "tallowy."



(9) Scorched. A more intensified flavor than "cooked" and imparts a burnt aftertaste.

(10) Stale, storage. Lacking in freshness and imparting a "rough" aftertaste.

(11) Utensil. A flavor suggestive of improper or inadequate washing and sterilization of milking machines, utensils or factory equipment.

(b) With respect to physical appearance--(1) Practically free. Present only upon very critical examination.

(2) Reasonably free. Present only upon critical examination.

(3) Moderately free. Discernible upon careful examination.

(4) Very slight pressure. Lumps fall apart with only light touch.

(5) Slight pressure. Only sufficient pressure to disintegrate the lumps readily.

(6) Natural color. A color that is white or light cream.

(7) Grainy. Minute particles of undissolved powder appearing on the surface of a glass or tumbler in a thin film.

(8) Unnatural color. A color that is more intense than light cream and is brownish, dull or grey-like.

(9) Lumpy. Loss of powdery consistency but not caked into hard chunks.

(10) Visible dark particles. The presence of scorched or discolored specks.

Supplement to U.S. standards for grades of nonfat dry milk (spray process); U.S. heat treatment classification.

58.538. Basis for obtaining heat treatment classification. Heat treatment classification is not a U.S. Grade requirement. Product submitted for USDA grading may be analyzed for heat treatment classification upon request of the applicant and the results shown on the grading certificate. Heat treatment classification will be made available only upon a U.S. graded product.

58.539. Nomenclature of U.S. Heat Treatment Classification. The nomenclature of U.S. Heat Treatment Classification is as follows:

U.S. High Heat.

U.S. Medium Heat.

U.S. Low Heat.

58.540. Basis for determination of U.S. Heat Treatment Classification. The whey protein nitrogen test shall be used in determining the heat treatment classification as follows:

(a) U.S. High-heat. The finished product shall not exceed 1.5 mg. underneath whey protein nitrogen per gram of nonfat dry milk.

(b) U.S. Low-heat. The finished product shall show not less than 6.0 mg. undenatured whey protein nitrogen per gram of nonfat dry milk.

(c) U.S. Medium-heat. The finished product shall show undenatured whey protein nitrogen between the levels of "high-heat" and "low-heat," (1.51 to 5.99 mg.).

COST OF PRODUCING DRY MILK IN LARGE  
SCALE PLANTS UNDER NEW TECHNOLOGY

by

ROBERT EUGENE SCHREPEL

B. S., Kansas State University, 1957

B. S., Kansas State University, 1963

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

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The process of drying skim or whole milk has grown to major importance in the dairy processing industry during and since World War II. Attention was focused on dry milk solids during the wartime period by the government's attempts to achieve greater efficiency in the use of fluid milk as a food product.

Postwar shifts in population and associated grade A milk requirements, and slackening of wartime requirements for condensed milk increased the need for efficient milk drying technology. Cooperatives and milk producer's associations sought means for handling and processing surplus quantities of milk. Milk drying capabilities of the industry generally seem characterized by steady expansion with undercapacity posing a problem more often than overcapacity.

The problem facing many plant managers can therefore be stated as one of undercapacity for existing drying facilities and steadily expanding operations. Solutions to this situation would appear to lie in alternatives for merger of present supplies with those of other large-volume processing plants, duplication of present low-volume processing equipment, or introduction of new, high-volume equipment.

The present study is intended to assist in providing information necessary for evaluation of these alternatives. The problem area defined for the study was summarized by two major hypotheses:

1. Acquisition costs for the newer, larger capacity drying facilities are not prohibitive, i.e., they do not provide an effective barrier to entry into the industry, and
2. The processing costs for the new facilities are such that an investment can be amortized in a relatively short period of time given an adequate milk supply and existing factor and product prices.



The analytical technique used for this study has been described as an "economic-engineering approach." The definitional framework used for the selection and evaluation of data was based upon "economic" concepts. Many cost element requirements were estimated by reference to "engineering" functions.

The milk drying process of a multi-product dairy manufacturing plant located in the Midwest was selected for study. The operating procedures of this "case study" plant were observed over a period of time and a detailed description developed. Individual stages, defined as "all productive services--durable or nondurable--that cooperate in performing a single operation or a group of minor but closely related operations," were identified for the case study plant.<sup>1</sup> Production run phases, defined as "related and identifiable production run activity contained within a given processing stage" were identified for each processing stage.

These phases were classified as either "fixed" or "variable" for a production run and total physical cost element requirements were calculated for each. A specified set of input factor prices were applied to the physical requirements and the resulting cost element costs were aggregated and manipulated by reference to the mathematical model developed for the study.

Average processing costs for the model plant ran from a high of about \$10.22 per hundredweight for the least efficient type of processing at 10,000 hundredweight of powder per year, to a low of about \$1.40 per hundredweight at 132,294 hundredweight annual powder production. Costs had declined to about \$1.91 per hundredweight for the most efficient type of processing, or about \$2.04 for the least efficient type, at an annual

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<sup>1</sup>Brems, 577.

production of 69,920 hundredweight. This annual production level corresponded to the two-year average volume of the case study plant and indicated that the plant was operating at a volume sufficient to benefit from many of the economies offered by the high-volume technology.

A comparison of processing costs thus developed for high-volume drying technology was made with costs developed by another study of low-volume technology. Reference to the two basic hypotheses stated for the study provided rough criteria for evaluation of the comparison.

It was concluded that the initial acquisition cost required for purchase of new equipment necessary for use of new drying technology probably would not be considered prohibitive by an established dairy plant of moderate to large size. The period of time required to recover the higher acquisition cost of the high-volume plant was progressively shorter at higher volumes of annual production. It was concluded that the recovery period would probably be short enough to be considered "reasonable" at an annual production corresponding to the maximum production of a single low-volume plant. It was further concluded that the recovery periods associated with all multiple installations of low-volume equipment could be considered quite "reasonable."

